Volume 7 October 1961 No. 8

FLIGHT IN THE FRINGES OF SPACE — A SYMPOSIUM
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Science and Engineering in Air and Space

Canadian Aeronautical Journal

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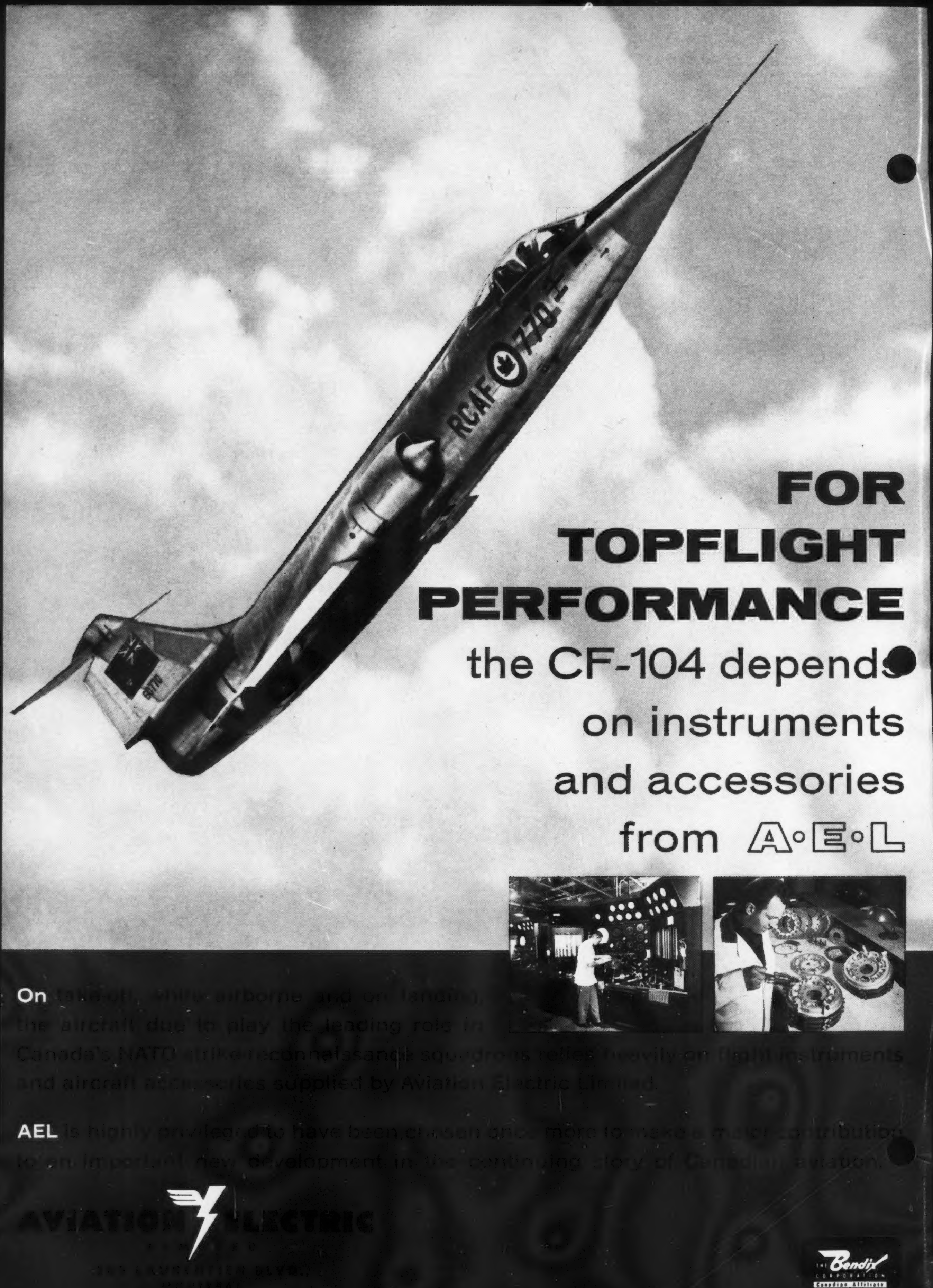
Published by the
CANADIAN AERONAUTICAL INSTITUTE
Commonwealth Building, 77 Metcalfe Street
OTTAWA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FLIGHT IN THE FRINGES OF SPACE

Aerodynamics **Physiology** **Navigation** **Flight Test**

A SYMPOSIUM

of the

CANADIAN AERONAUTICAL INSTITUTE: TEST PILOTS SECTION

to be held at

R.C.A.F. STATION UPLANDS

on the 17th and 18th November, 1961

The full programme is given on page 314 of this issue.

REGISTRATION

The visit to the I.A.M. Toronto is restricted to members of the Test Pilots Section. However the remainder of the technical programme is open to all C.A.I. members holding current membership cards.

Advance Registration is necessary for those intending to visit the I.A.M. The attached slip should be used for this purpose.

On the 18th November Registration will take place in the Foyer, Officers' Mess, at R.C.A.F. Station Uplands at 9.00 a.m.

TRANSPORT

Those intending to visit the I.A.M. from Ottawa report to Air Movements Unit Passenger waiting room at the 412 Transport Squadron Hangar, R.C.A.F. Station Uplands at 8.00 a.m. on the 17th November.

Members of the Section joining the party at the I.A.M. may return in the aircraft to Ottawa for the remainder of the programme, if space permits.

DRESS

Military personnel will be required to wear uniform for the trip to Toronto but at other times dress is optional.

COCKTAILS AND DINNER

Cocktails will be served in the Officers' Mess, R.C.A.F. Station Uplands, from 7.30 p.m. on the 17th November, followed by a buffet Dinner at 8.00 p.m. There will be a social period and dancing afterwards. Dress will be informal.

C.A.I. members and their ladies are most welcome. However members' guests can be admitted only as space permits; unfortunately the facilities of the Mess are limited.

Inclusive tickets, price $6.00 a couple or $3.50 single, must be ordered on the attached slip, before the 14th November. Cheques and money orders should be made payable to the Canadian Aeronautical Institute.

BEFORE THE 14th NOVEMBER

Mail to: Squadron Leader J. E. Hanna,
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Ottawa 3, Ontario.

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Canadian Aeronautical Journal

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Subscription—$4.00 a year. Single copies—50 cents each
Copies prior to 1959—$1.00 each
Bound Volumes—Orders for binding readers' own copies will be accepted in January and February, 1962, at $5.00 a volume.
Published monthly, except July and August

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All communications should be addressed to The Secretary, Canadian Aeronautical Institute, 77 Metcalfe St., Ottawa 4, Ontario, Canada

Authorized as second class mail, Post Office Department, Ottawa

Printed by The Runge Press Ltd., Ottawa, Ontario, Canada

CANADIAN AERONAUTICAL INSTITUTE

JOURNAL

W. RUPERT TURNBULL LECTURER

Mr. J. C. M. Frost

Mr. J. C. M. Frost, Chief Design Engineer, VTOL, Avro Aircraft Ltd., delivered the seventh W. Rupert Turnbull Lecture on the 25th May, 1961, in Toronto. The Lecture appears on the following pages.

Mr. Frost was born in England in 1915 and was educated at St. Edward's School, Oxford. He served an apprenticeship at Airspeed Limited and in 1936 he joined Westland Aircraft Limited, working on the Whirlwind. In 1940, after two years on wind tunnel work at Blackburn Aircraft, he went to Slingsby Sailplanes, where he was responsible for the conception and design of the Hengist troop-carrying glider. From 1942 until he came to Canada in 1947, he was at De Havilland Aircraft Limited; he was associated with the Mosquito, Hornet and Vampire designs and, finally, as project engineer, with the DH 108 Swallow.

On arrival in Canada, he was placed in charge of the design of the Avro CF-100 and saw it through several Mark Nos. The Avro Special Projects group was formed in 1953, under his leadership, to study GETOL/VTOL and from this work the Avrocar emerged.

CANADIAN AERONAUTICAL INSTITUTE

THIS IS PRESENTED TO

J.C.M. Frost

WHO DELIVERED THE

W. Rupert Turnbull Lecture
for 1961

ON THE OCCASION OF

The Annual General Meeting of the Canadian Aeronautical Institute held in Toronto, Ont., on the 25th and 26th May, 1961.

The Lecture was established in 1955 by the Canadian Aeronautical Institute to commemorate annually the pioneering work in aeronautical engineering carried out by Dr. Rupert Turnbull of Rothesay, New Brunswick.

THE SUBJECT OF THIS SEVENTH LECTURE WAS

"The Canadian Contribution to the Ground Cushion Story"

DATE: 25th May 1961

David Boyd
PRESIDENT

SECRETARY

THE CANADIAN CONTRIBUTION TO THE GROUND CUSHION STORY†

by J. C. M. Frost,* A.F.C.A.I.

Avro Aircraft Limited

ORIGIN OF THE GROUND CUSHION

It often happens that new ideas are thought of and worked upon in different parts of the world at the same time without one group having any knowledge of the other's activities. In many cases this is due to a general rise in the level of the state of the art, so that there are numbers of groups working who are all on the verge of taking the next step within the same period.

In the case of the ground cushion, this was not so, since it was technically possible for the Wright Brothers to have built a ground cushion vehicle at the same time they flew the first airplane.

It is therefore surprising to find at least three groups working on ground cushion concepts between the years 1953 and 1956, apparently without knowledge of each other. Avro discovered the ground cushion in 1953 while studying the flat rising vertical takeoff airplane. Cockerell came on it in England in 1955 while making efforts to reduce the drag on ship hulls, and Carl Weiland of Switzerland in about 1956.

In actual fact, Toivo Kaario of Finland built and tested the ram wing, a first cousin to the ground cushion, as early as 1935, and in 1949 he built one with a fan in it which must have been the first example of a ground cushion machine supplied by a plenum chamber, as distinct from the annular jet used by Avro and Cockerell.

It is unfortunate that our sights were set on developing a supersonic vertical takeoff aircraft when Avro stumbled on the ground cushion, otherwise we might have paid more attention to its possible uses as an amphibious surface vehicle, rather than the undercarriage for an aircraft. We did realize its potential as a substitute for the wheel and the caterpillar track; we also realized that it would operate over water; but we missed its potential as a method of improving the performance of water-borne craft (which Cockerell was so quick to promote with the Hovercraft).

At first sight the problems of overland operation looked formidable. To operate over roads would require the ability to drive accurately and not get blown off course; in turning a corner there must be no sideslip; and to cross unprepared terrain a ground clearance of at least 4 ft would be necessary. All these problems we decided to tackle later. For the time being we were aircraft engineers and the possibility of raising a supersonic aircraft vertically 15 ft into the air, with its thrust only two-thirds of its weight, was attractive enough.

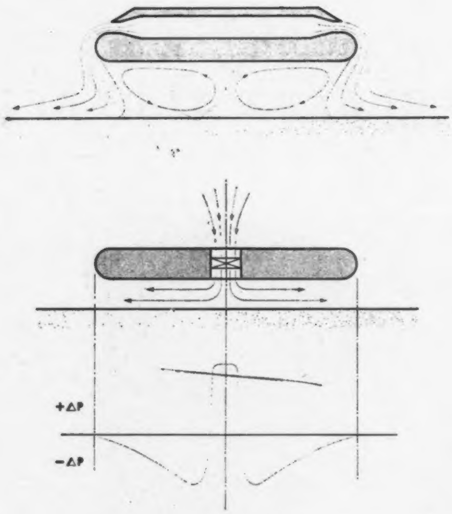


Figure 1
Ground effects

We had been trying for quite a while to find an arrangement using aerodynamic subtlety, rather than the jet thrust brute force method that others were experimenting with. Dr. Griffiths of Rolls-Royce was proposing the flying bedstead, but it had not flown. We had just graduated from the tail-sitter type and were in the process of studying a circular version of a flat riser with a peripheral jet when we first discovered we had a ground augmentation.

We immediately explored this to its two more obvious extremes, as shown in Figure 1, the upper diagram representing a section through the type of model we were using, with the jet issuing from a peripheral slot and being deflected downwards in a circular curtain by Coanda effect on the curved lower lip of the nozzle, so producing a positive ground cushion with a relatively thick jet curtain. The lower

†The W. Rupert Turnbull Lecture for 1961 was presented at the Annual General Meeting of the C.A.I. in Toronto, on the 25th May, 1961.

*Chief Design Engineer, VTOL

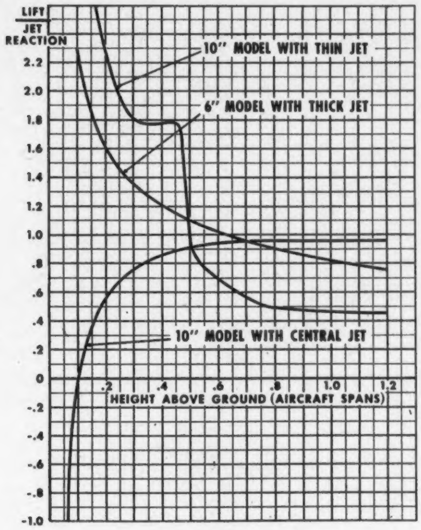


Figure 2
Comparison of ground effect curves

diagram represents a circular body, with the jet issuing from its center, producing a negative ground cushion, or sucking, on to the ground.

Figure 2 shows two curves for the positive ground effect: one with a thick jet producing a fairly smooth curve, and the other a thin jet showing the characteristic step associated with a sudden change of flow pattern. The third lower curve shows the negative ground effect.

During this period our studies were being funded by the Canadian Government and it says a great deal for the farsightedness of such people as Dr. O. M. Solandt and Dr. J. J. Green of the Defence Research Board that we were allowed to continue with what, at that time, must have seemed like optimistic crystal gazing. It is thanks to these people and the directors of A. V. Roe Canada Limited that this country now holds what may one day prove to be the key patent in the whole principle of the ground cushion concept.

CHOICE OF AERONAUTICAL APPLICATIONS FOR THE GROUND CUSHION

Having discovered this method of augmenting lift it was necessary to consider what type of aircraft would benefit most from its application. There were, of course, a number of factors involved. Early tests indicated that the circle was the optimum shape for a peripheral jet and that if this were gradually stretched into an ellipse the ground cushion so produced became progressively less effective as the aspect ratio of the ellipse increased. For aspect ratios much in excess of 4, and for the size of wing we were prepared to contemplate (effectively 30 ft diameter), it was not possible to obtain a useful augmentation at a worthwhile height.

There would, therefore, be some aerodynamic penalty in applying the ground cushion to the wing of a subsonic airplane of this scale.

For an aircraft which would cruise supersonically, there was little disadvantage in low aspect ratio. So it

Figure 3
Jet flap model — tested in Woodford tunnel

was decided to apply the cushion to the wing of the supersonic aircraft, with the jet exhaust leaving vertically from the periphery of the wing for takeoff and able to be directed rearwards to provide thrust in forward flight. The jet sheet so formed issuing from the trailing edge gave the wing the benefits of a jet flap. At that time Davidson and Stratford of the National Gas Turbine Establishment had not published their work on the jet flap. We were, however, aware of some of the advantages associated with this arrangement because of tests we had carried out ourselves on a model wing using a jet flap which we tested in the Woodford tunnel of A. V. Roe Limited, Manchester, England, in June 1953 (see Figures 3 and 4). This took place during one of our trips to England which occurred from time to time to confer with associates of the technical group at A. V. Roe Limited, with the Royal Aircraft Establishment, and any other organiza-

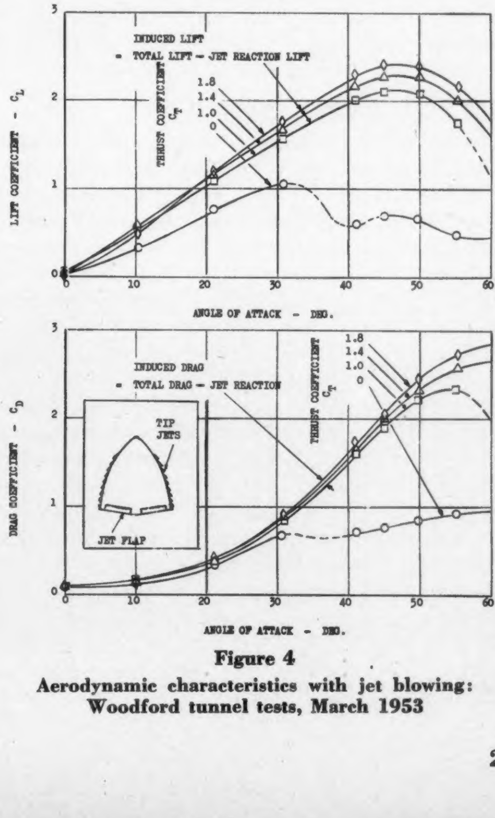


Figure 4
Aerodynamic characteristics with jet blowing: Woodford tunnel tests, March 1953

tion that was qualified to throw light on what we were trying to do. Many interesting and useful discussions took place and, as a group, we feel most indebted to those who took the trouble to listen to us.

Having reconciled ourselves to a low aspect ratio wing, it seemed a pity not to go all the way and use a circular planform. We argued that the circular wing would be the best compromise in which the poor subsonic lift/drag ratio – due to its low aspect ratio – would be largely offset by the fact that the circle provided an optimum duct system with minimum internal aerodynamic losses. The circle was the best shape for an annular ground cushion jet, and the optimum shape for structural simplicity and lightness. There were those who criticized us for this, on the basis that very little was known about the external aerodynamics of the circle, whereas a delta shape could be used on which a wealth of aerodynamic information existed.

We were sympathetic to this argument, but had been put off by a test carried out on a delta shape in which we found it difficult to obtain an even pressure distribution around the periphery of the nozzle. This could be further aggravated by the fact that the various diffusion passages generating from a central fan would all be different lengths, causing different pressure levels to exist throughout the system.

WELCOME ARRIVAL OF AMERICAN INTEREST

Still under the support of the Canadian Government, a number of supersonic aircraft, using wings of circular planform ranging in thickness from 2% to 8%, were then studied.

At this juncture Dr. Solandt was able to interest General D. C. Putt, then head of the United States Air Force Air Research & Development Command, in our activities. The USAF interest resulted in our being awarded a study contract involving subsonic and supersonic wind tunnel testing, static testing of the ground cushion and configuration studies.

EARLY TESTS ON THE ANNULAR JET

Now, for the first time, we had money available to design a proper rig on which to start studying the ground cushion. A picture of this first rig is shown in Figure 5. The model was mounted centrally on the lower end of a 2 inch diameter vertical downpipe which in turn was mounted on a 2 inch diameter horizontal pipe. The horizontal pipe was cut near the downpipe and a 12 inch diameter wooden disc was fixed flange-wise around the end nearest the downpipe. The other end was supported in a sheet metal bracket, which faced the wooden disc to form an air bearing. The disc, the downpipe and the model were supported by three ring dynamometers connected to the downpipe and to pins on the bracket. Compressed air was supplied to the model through the horizontal pipe and the downpipe. A portion of the air supply escaped radially between the air bearing surfaces with the result that the air bearing could support large forces and moments normal to the bearing surfaces, while offering negligible resistance to forces and moments parallel to these surfaces. The latter were supported by the dynamometers.

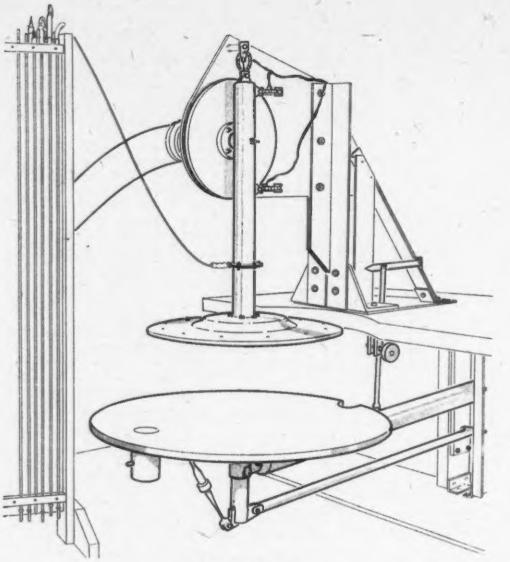


Figure 5
Ground effects model

A pitot head and a static tap were located at the lower end of the downpipe. The ground was represented by a circular flat plate below the model, which could be raised, lowered, and tilted. Pressures were measured with a multiple U-tube manometer, and forces measured by strain gauges mounted on the dynamometers connected through a selector switch to a single Baldwin SR 4 strain gauge meter.

A very great number of tests were carried out on this rig, and variations of it, over the three years between 1955 and 1958. During this period we altered every variable we could think of. Some of the more typical results obtained are shown in Figures 6, 7 and 8.

This was probably the most frustrating time of all, since this attractive idea, which on the face of it could form a substitute for both the wheel and its suspension and seemed such a simple system, turned out to be as difficult an aerodynamic problem as it is possible to find. We had nobody but ourselves to blame for the

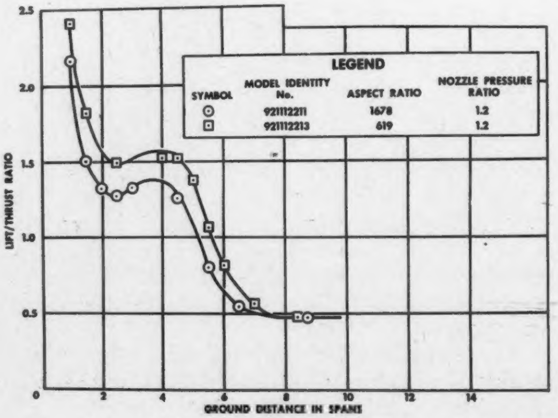


Figure 6
Effect of nozzle aspect ratio on lift/thrust ratio

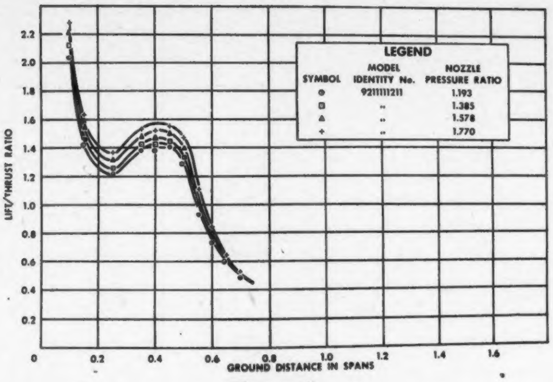


Figure 7
Effect of nozzle pressure ratio on lift/thrust ratio

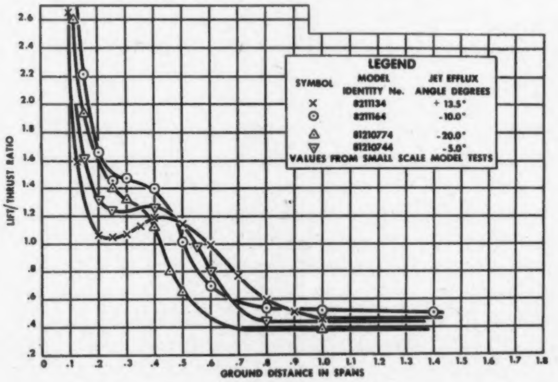


Figure 8
Effect of jet efflux angle on lift/thrust ratio

troubles we got into since, by virtue of the route we had chosen, we were unknowingly starting with the hardest end of the problem first. Cockerell, in his promotion of a water-borne vehicle, could initially be satisfied with a height/diameter ratio which did not exceed 0.06; we, on the other hand, started with our vehicle on its wheels at this height and were counting on realizing augmentations of 1.4 to 1.7, which we had measured at an h/d of 0.5. We were also hopeful of finding a way to substitute this cushion of air under the wing for the basic aerodynamic lift of the wing itself, without destroying the one before the other was in a position to take over, and also to satisfy the requirements of stability while this process was going on.

We very quickly learned that the annular jet cushion, although quite stable close to the ground, becomes progressively more and more unstable as the ground height is increased, and that before leaving the influence of the ground altogether, a height — which we named the critical height — is crossed where a sudden basic change in the flow pattern takes place. This change is associated with considerable hysteresis. The critical height at which this change takes place is altered by a number of variables:

(i) jet angle to the base,
(ii) vehicle angle to the ground,
(iii) forward speed of the vehicle,
(iv) undersurface contour, and
(v) jet aspect ratio.

Also, with a simple annular jet, once the influence of the ground is removed, the thrust in free air is reduced by as much as 50% of the momentum thrust of the nozzle by the separation which is present on the undersurface of the body.

All these problems rapidly became apparent within the first year of testing, and the situation was further complicated by the difficulty we experienced in determining exactly what the momentum thrust at the nozzle was, which continually led to testing inconsistency. The problem was that, although it was easy enough to measure the mass flow, it was hard to arrive at the total pressure at the nozzle — the other quantity required to compute the momentum thrust. This was due to the fact that the nozzle was rarely, if ever, exhausting to atmospheric pressure, and there was usually a pressure gradient across it. In an attempt to get around this problem, we resorted to making the model into a plenum chamber by ignoring the flow over the upper surface — which under static conditions did not amount to very much — and making the model violently out of scale in thickness, as is indicated in Figure 9. This helped considerably.

As mentioned, we found all these troubles within the first year, and have been trying ever since to get around them. Though we are not entirely satisfied with all the solutions we now have, we feel that the more basic problems can be solved.

Since we started testing, many other organizations on both sides of the Atlantic have carried out similar research, and the basic fundamentals of the annular jet are now well understood. Acceptable theories have also been evolved which explain and predict its general behaviour in a satisfactory manner. The first theoretical work to be published in this regard was that by Harvey R. Chaplin, of the David Taylor Model Basin, in his paper entitled, "Theory of the Annular Nozzle in Proximity to the Ground", July 1957.

Other work on annular jets has recently been carried out in Canada under Government sponsorship. At the Institute of Aerophysics, under the direction of Dr. G. K. Korbacher, studies were carried out by Mr. D. B. Garland on a model of an inwardly inclined annular jet, with the object of investigating the effects of changes in aspect ratio and pressure ratio on such an arrangement. Also, at the National Aeronautical

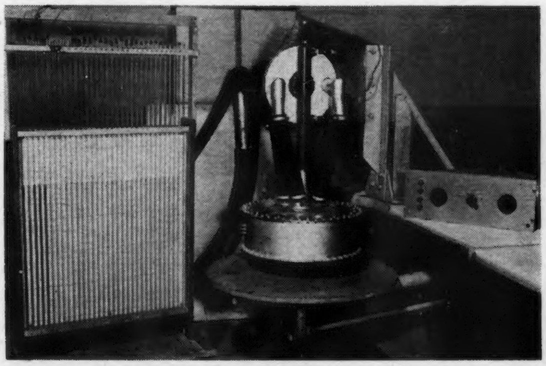


Figure 9
Ground cushion test rig using plenum chamber model

Establishment in Ottawa, a small scale triangular shaped ground effect vehicle has been built and is now being flight tested under the direction of Mr. A. D. Wood.

Interest to date, however, has been largely focussed on problems associated with the lower values of height/diameter ratio in the vicinity of 0.15 downwards; the problems to be tackled in the region above this height, particularly stability and economy, have still only been seriously approached by very few besides Avro.

The most serious problem encountered in the higher *h/d* values is the dynamic instability in pitch, roll and heave, which becomes worse as the value is increased. This is largely due to the very considerable reduction in damping which takes place as the value of *h/d* is increased.

We went to some trouble to measure the damping in heave, which we did with the model shown in Figure 10. This was a circular model, 10 inches in diameter, with a peripheral jet of compressed air which was supplied through a long flexible pipe. The model was suspended vertically from a long-travel, low-rate, steel spring. The model was then allowed to bounce up and down freely on the spring and the number of vertical oscillations to damp to half amplitude were counted. This was done for different ground heights and different jet arrangements etc. A typical curve showing the results is indicated in Figure 11.

The greater part of our studies on the ground cushion in the latter years has been devoted to combatting problems in this area of static and dynamic stability.

To obtain stability in pitch and roll, we tried various alternatives too numerous to mention. The most

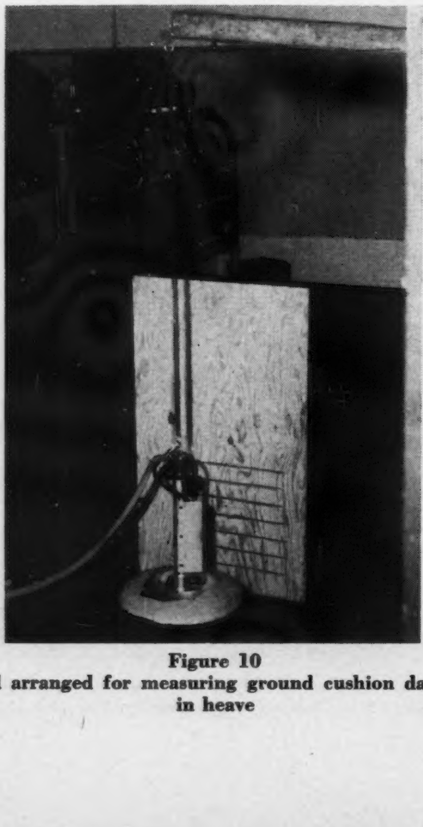


Figure 10
Model arranged for measuring ground cushion damping in heave

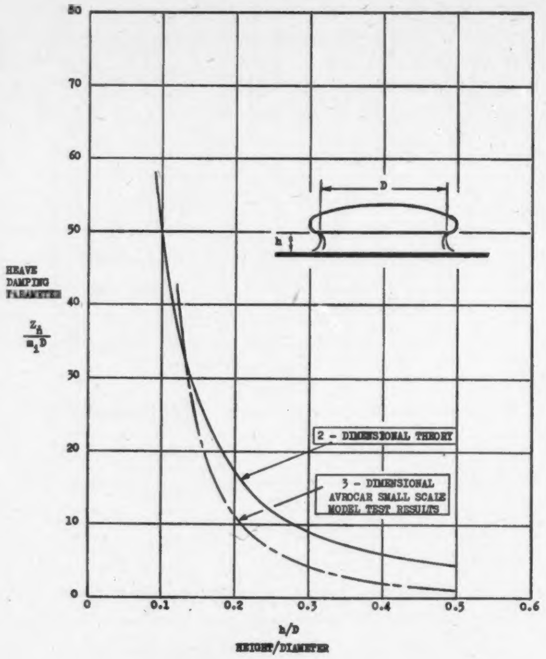


Figure 11
Heave damping

successful of all these was the introduction of a central jet, or inner annular jet ring (Figure 12). We found that an inner jet equal to ¼ of the momentum of the outer peripheral jet would be enough to completely stabilize the system statically and dynamically, from close to the ground until the whole arrangement becomes neutrally stable (ignoring sideslip effects which make it stable) when out of ground effect. The presence of the central jet also extended the height of the ground cushion (Figure 13). Combinations of central jet with undersurface contour also showed some promise with respect to reducing the strength of central jet required to produce stability. A three pad system was tried with considerable success. However, dividing the cushion area in order to have three pads appreciably reduces the height at which it is possible to have a given augmentation, so that this arrangement, though probably the most successful of all, was not very popular on that account.

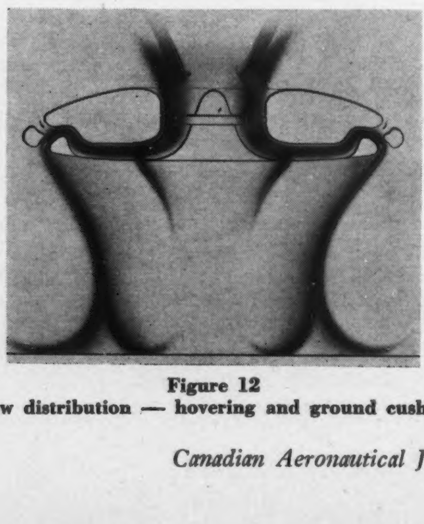


Figure 12
Flow distribution — hovering and ground cushion

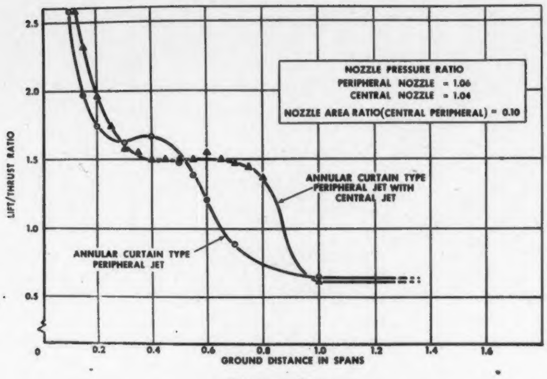


Figure 13
Effect of central jet on lift/thrust ratio

WIND TUNNEL TESTS ON THE CIRCULAR PLANFORM

Parallel with the work on the static ground cushion test rig, we built three different wind tunnel models, one subsonic and two supersonic.

The subsonic model was 5 ft in diameter and was tested half-plane and wall mounted in the 20 ft diameter tunnel at WADC, Dayton.

The other two were supersonic models and were tested in the Naval Research Tunnel at MIT. One was half-plane and wall mounted on a reflection plane, and the other, a full-plane model, was sting mounted.

The subsonic and supersonic half-plane models were equipped with peripheral jets supplied by compressed air, which was fed through a pipe in a special wall mounted balance on the reflection plane side. It was arranged that the peripheral jet could be deflected either downwards as a cylindrical jet curtain, or backwards past the trailing edge in the form of a jet sheet. The jet sheet could be deflected upwards or downwards about the trailing edge in the form of a jet flap, or elevator.

Typical results for lift, drag and pitching moments with a subsonic and a supersonic circular planform are shown in Figures 14 and 15. Further details on these models are still classified and cannot be discussed here. However, a total of 900 hrs of subsonic wind tunnel testing time and 250 hrs of supersonic tunnel testing time were logged, so that an extensive background on the behaviour of the circular planform wing in forward flight was obtained.

Up to this time the only work on circular planforms we could find was that by Charles Zimmerman, in a subsonic study on a circular planform Clark Y section wing. To the best of our knowledge nothing on the supersonic behaviour of circular wings existed.

REQUEST FOR PROPOSAL BY US ARMY

In 1956, while involved with the study program for the USAF, we received a visit from members of the US Army.

The Army were interested in vehicles which would provide them with more mobility. They concluded that flying was the only way to obtain completely unrestricted movement. However, they had to be able to fly close to the ground because the ground was their natural environment and offered protection and a chance of concealment.

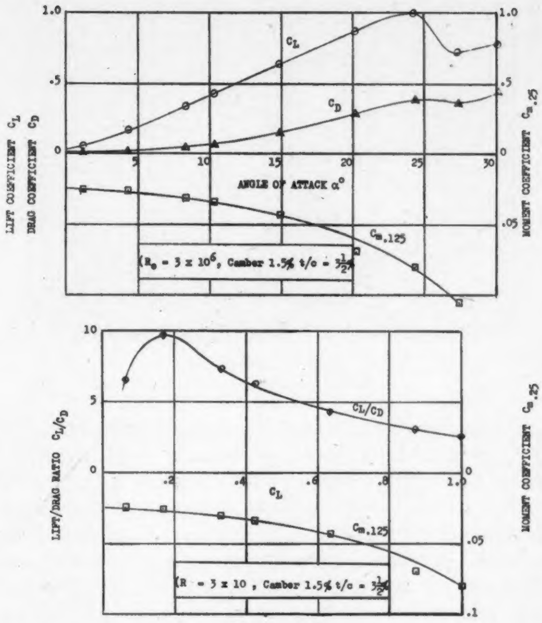


Figure 14
Measured subsonic characteristics for a thin cambered biconvex aerofoil of circular planform

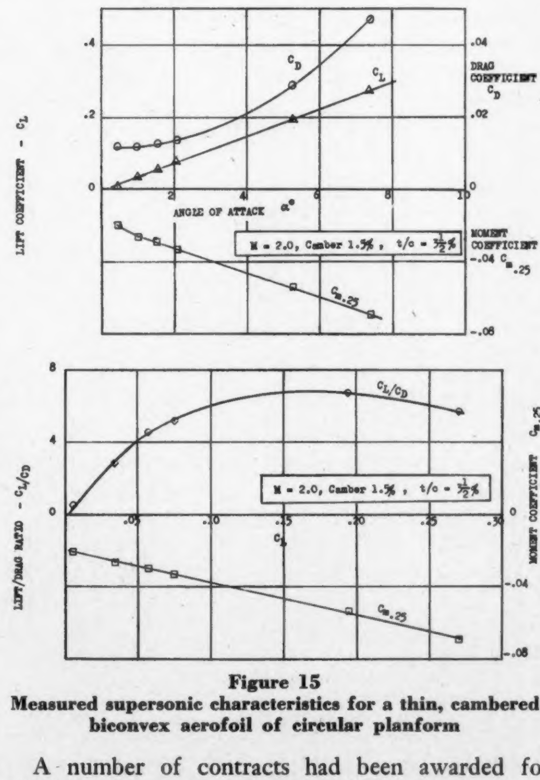


Figure 15
Measured supersonic characteristics for a thin, cambered biconvex aerofoil of circular planform

A number of contracts had been awarded for vehicles which were expected to fulfil this function; these were mostly motivated by ducted fans, and became known as 'flying jeeps'.

The US Army had heard about our ground cushion activities and were optimistic that a vehicle using this principle would be more suitable. We studied the problem for a few weeks and made an

Figure 16
Avrocar

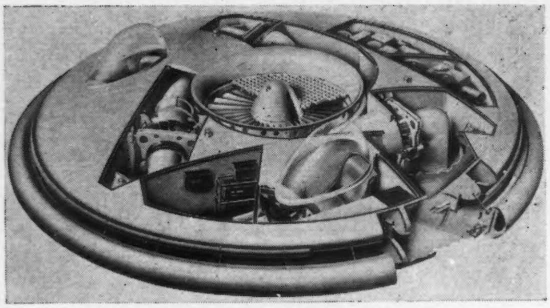


Figure 17
Structure cutaway

unsolicited proposal which we thought would fit. This was for a circular all-wing machine which could fly clear of the ground (using aerodynamic lift), as well as loiter close to the ground in the ground cushion. The proposal was well received, and some months later we obtained a contract to build two such machines as research vehicles. We had thus obtained our first financial support to build flying hardware. An artist's impression of two of these vehicles being used on an Army reconnaissance mission is shown in Figure 16.

DESCRIPTION OF THE AVROCAR

This vehicle became known as the Avrocar (see cutaway Figure 17). It was 18 ft in diameter, a circular wing with a 20% elliptical section and 2% camber, and its gross weight with 2,000 lb of useful load was estimated at 5,650 lb.

The power was supplied by three J69-T-9 turbojet engines, which we estimated would provide the following performance:

Speed and Climb		
Maximum speed at sea level	225 kts	
Rate of climb at sea level	4,500 ft/min	
Ceiling (limited by no oxygen for crew)	10,000 ft	
Range at sea level	145 nm	with 1,670 lb payload
Range at 10,000 ft	180 nm	

The leading dimensions and weights were as follows:

Diameter	18 ft
Gross wing area	253 sq ft
Aspect ratio	1.27
Thickness/chord ratio	20%
Maximum fuel capacity	177 US gals
Maximum gross weight for VTOL	5,650 lb
Empty weight	2,820 lb
Wing loading at max gross weight for VTOL	22.2 lb/sq ft

The US Army required that this vehicle should be able to take off vertically into free air and hover out of the influence of the ground. This was not the best concept for a ground cushion vehicle. It would have been more economical to have it take off into aerodynamic flight only from the ground cushion. The requirement to hover out of ground effect involved installing considerably more power than otherwise would have been necessary.

In proposing a subsonic circular wing we had some misgivings with respect to the low aspect ratio. It was, however, a compromise inasmuch as the vehicle was required to maneuver close to the ground among obstacles etc, and it was probable that equal periods of time would be spent hovering in the ground cushion and in aerodynamic flight. Also, the fact that it was designed to have vertical takeoff helped justify this compromise, since aspect ratio – the all important parameter when considering translational takeoff over a fixed height from the ground – would not be so noticeable by its absence.

The helicopter was the obvious competition, so it was necessary to see how the circular wing would compare with this. Hovering in the presence of ground augmentation, the Avrocar lift/hp would be comparable to the helicopter. Wind tunnel tests on circular planforms had indicated subsonic lift/drag ratios for thin wings as high as 11; we thought it reasonable to expect values of 7 on the Avrocar with its 20% thick section. This would give the Avrocar an advantage in forward flight since the lift/drag ratio of the helicopter is of the order of 4. We were hopeful, too, of developing up to speeds of 240 kts, well above the present range for helicopters.

Hovering out of ground effect, the vehicle would be vastly inferior on a basis of lift/hp, due to the very high disc loading on the Avrocar fan. However, we did not see the necessity for flying long in this condition.

The Avrocar was equipped with a 5 ft diameter fan situated in its center, exhausting via an internal duct system to a peripheral nozzle. The fan was driven by means of a tip turbine which used the exhaust from three J69-T-9 engines (see Figures 18 and 19). These engines, which we were using as gas generators – a function for which they were not designed – were not technically the most ideal for the purpose, the specific weight being high compared with other more sophisticated engines of that time; and a higher total pressure in the jet exhaust would have enabled us to obtain more work on the single stage fan turbine for the same mass flow and temperature. This is not a criticism of the engine, since there was a more modern version just becoming available which we could have had if we had wanted it. We chose the J69-T-9 because it was relatively easy to obtain, and was extremely rugged and dependable; at the time of writing,

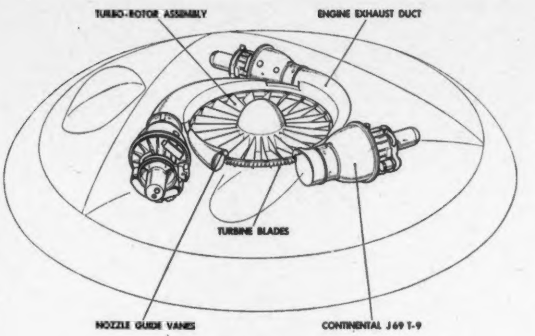


Figure 18
Engine installation

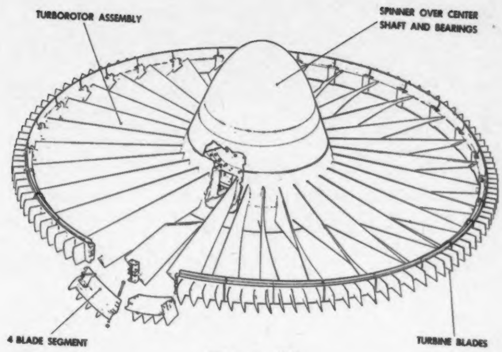


Figure 19
Turborotor assembly

we have not had one failure for which the engine could be blamed.

We took a risk in choosing the method of driving a fan with a tip turbine because of the large installed power we had to transmit. The three J69-T-9 engines, together, were designed to produce 3,000 shaft hp. The tip drive, if we could develop it, seemed to be lighter and simpler than becoming involved with gears, clutches, free wheel devices etc.

The fan with its tip turbine was designed and built for us by Orenda Engines Limited. It had hollow sheet metal fan and turbine blades, and a simple central bearing arrangement using only two taper roller bearings, a system we had developed earlier on a previous test rig. In 300 hrs of test running not one mechanical failure occurred which could be attributed to the fan or turbine.

Orenda Engines Limited also built an elaborate rig (Figure 20) to test the fan and develop it to preflight rating standard before installation in the Avrocar. On this rig we used one Orenda engine instead of the three J69's. This was to give more flexibility to the test and, since the Orenda engine developed greater power than the three J69 engines put together, it would provide an opportunity to test the fan under overspeed conditions. What mechanical trouble did occur was due to this rig, from which, on a few occasions, bits of metal etc would fall and find their way through the fan. At no time did this result in a catastrophic failure of the rotor. This was a remarkable achievement on the part of Orenda, and represents another Canadian 'First'.

General Electric have since designed and built an almost similar tip driven fan which is now operating successfully. They are advocating this for installation in the wings or fuselage of aircraft to provide a vertical takeoff capability.

The Avrocar fan was designed to handle 550 lb of air/sec at a pressure ratio of 1.07 to 1, and was driven by an impulse type turbine situated around its rim. The three exhausts from the J69 engines each occupied 120° of the turbine inlet area, and each engine had its own jet pipe fashioned in the shape of a tusk (Figure 18) and separate from its neighbour, so that should one engine fail the back pressure of the other two would not be fed back through the stopped engine. The hot exhaust from the turbine was mixed with the cold flow from the fan in a duct immediately below the fan.

This duct passes from the bottom of the fan below the cockpits, engine bays, and cargo compartments, to the peripheral nozzle around the circumference of the vehicle (Figure 21). The mixed temperature of the air in this duct was calculated to be 100°C under design conditions.

The first serious problem encountered on the Avrocar was the discovery, on the Orenda rig, that the mass flow being passed by the fan was only 400 lb/sec. This resulted in a loss of about ⅓ of the thrust and the exhaust temperatures increased from the estimated figure of 100°C to 160°C. The cause of this deficiency was due to the fact that we were mixing the hot high energy exhaust from the turbine with the cold lower energy flow from the fan on the first bend in the duct system, and the hot flow was separating from the wall of the duct and backing up the delivery from the fan. This was a serious situation since the Avrocar was practically built when the trouble was discovered, and though the cure was a fairly obvious one, namely, to carry the hot flow further around the bend, it was too late to carry it out on the Avrocar without a major structural modification.

It was decided therefore to carry on and fly the Avrocar at a reduced thrust level in the ground cushion, and modify the duct at a later date to pick up the missing thrust.

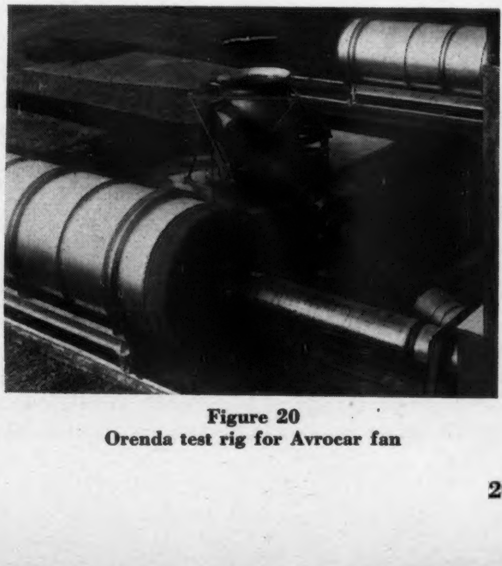


Figure 20
Orenda test rig for Avrocar fan

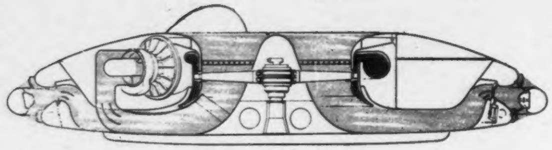


Figure 21
Cross-section general arrangement — Avrocar 1

This loss of mass flow meant that we would not be able to hover out of ground effect.

The second trouble encountered was associated with the intakes for the J69-T-9 jet engines, which were originally designed to be fed from the duct (Figure 21) so that the engines would be rammed to the extent of the pressure ratio on the main rotor (1.07 to 1). It was naturally important that these intakes should not consume any of the hot exhaust from the tip turbine of the main fan.

So that this would not happen, a structural ducting arrangement of radial ribs etc was devised at the local areas on which the intakes were breathing. The design of this was one of those clever arrangements and, as usually happens in such matters, it did not work.

On our first attempts to start the engines the intakes overheated and it was not possible to accelerate them past idling without exceeding their limiting jet pipe temperatures. This trouble was not altogether unexpected, and a fairly quick cure was already designed and partially manufactured.

What we had to do was turn the right angle ducts of the J69 intakes upwards, and allow the engines to breathe directly from the upper surface of the wing. In doing this we lost the benefit of ramming the engines with the main fan, which was calculated to lose 5% of the total thrust.

The ducts carrying the gases from the fan and turbine formed an integral part of the vehicle structure – a radial rib arrangement – in which the radial ribs with top and bottom skins formed at the same time a stiff structure for the vehicle and a natural diffuser passage for the gas. This passage started at the center under the fan and terminated with a sudden contraction to the final nozzle at the rim.

At the final nozzle the gases were exhausted to atmosphere either perpendicularly downwards in the form of a circular curtain, or in a generally backward direction in the form of a jet sheet. The direction of the jet was controlled by a mechanical stabilizer system, mentioned later.

GROUND CUSHION PROBLEMS ENCOUNTERED ON THE AVROCAR

The design requirements for the Avrocar were that it should be able to hover or loiter within ground effect and, when required, rise vertically and hover away from this influence. In order to do this a stable, or near stable, ground cushion in pitch and roll was essential.

The design of the Avrocar, therefore, included an outer peripheral jet, with the addition of a central jet which would be used during hovering, and which

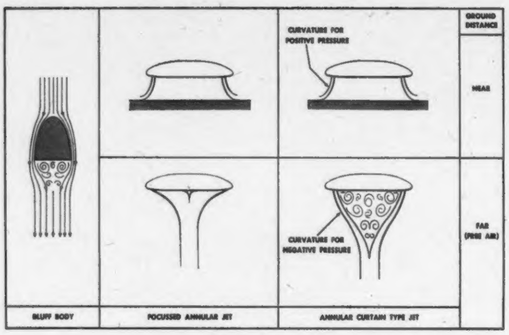


Figure 22
Bluff body analogy

could be closed off in forward flight. Model tests indicated that a central jet with a strength of 20% of the momentum of the peripheral jet would be sufficient to reduce the unstable margin, so that at all heights above the ground the vehicle, in combination with its control system, would display the characteristics of stability or well damped neutral stability.

The problem of rising out of ground effect was more difficult. As explained earlier, one of the troubles encountered with the annular jet ground cushion was that out of the influence of the ground the lift produced by the jet is only 50% to 60% of the jet momentum at the peripheral nozzle, and that this loss is due to the separation caused on the undersurface of the wing or body, making itself felt in the form of a negative pressure. Out of ground influence the peripheral jet curtain tends to coalesce into a solid jet at some distance below the base, forming a flow system which looks like a wine glass with the separation taking place within the bowl and the coalesced portion forming its stem (see Figure 22).

We had done tests to see whether this loss of lift in free air, due to this negative pressure on the base, could be recovered by interrupting the jet curtain so that the base area would be vented to atmosphere. The effect of doing this is shown in Figure 23, and it will be seen that as one method it was reasonably effective. However, it was also obvious that it would not do for the Avrocar. To interrupt sections of the peripheral jet would not only reduce the thrust by decreasing the nozzle outlet area but would at the same time push the fan nearer the surge line.

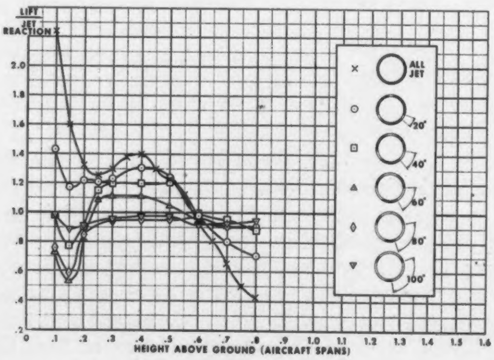


Figure 23
Effect of local jet blockage

Figure 24

It had occurred to us that if the loss of lift in free air was caused by a separation, the best way to cure the trouble was not to have a separation, or to attach the flow to the undersurface (Figure 22).

This can be done, if the annular jet escaping downwards from the bottom of the vehicle is progressively deflected inwards towards the center. It will be found that when the jet has been deflected from the vertical through about 60° towards the center, the inner edge will attach itself to the lower surface of the body, the whole jet meeting in the center and being deflected vertically downwards in an escaping column — or tree trunk of air (Figure 24). The air outside will be drawn in around it forming an unseparated flow system. Model tests using this arrangement showed that the lift measured was between 85% and 95% of the momentum existing at the peripheral nozzle (see Figure 25). This was the sort of loss we could tolerate, and in estimating the free air hovering characteristics of the Avrocar we had allowed for 15% to 20% of extra thrust for such eventualities.

The characteristics of the focussed annular jet are slightly different in the ground cushion to those of the unfocussed jet. In the first place the ground cushion does not extend to such a high value of *h/d*, starting approximately at a value of 0.4 with the lift increasing gently up to an *h/d* of 0.3. From there on the cushion lift produced by the focussed jet increases more rapidly and reaches higher values than the unfocussed type; and when the vehicles reaches an *h/d* of about 0.2 there is a flow of configuration change and the jet suddenly becomes unattached from the lower surface, jumping out to form a conventional annular jet curtain with a cushion area of separated flow in its center. From the 0.4 value of *h/d* to the 0.2 value, the central tree trunk of air is progressively thickening (Figure 26). The 0.2 height at which the jet separates from the lower surface is the critical height for that degree of focussing. As mentioned earlier, all annular jets have a critical height and the value of this depends mainly on the angle at which the jet leaves the lower surface of the vehicle.

Figure 27 shows a family of generalized curves, indicating how the value of lift augmentation varies against *h/d* for a progressive change in the angle at

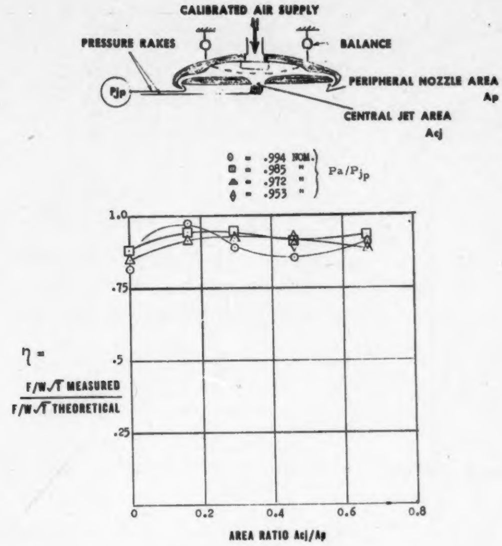


Figure 25
Effect of central jet on thrust efficiency of focussed jet

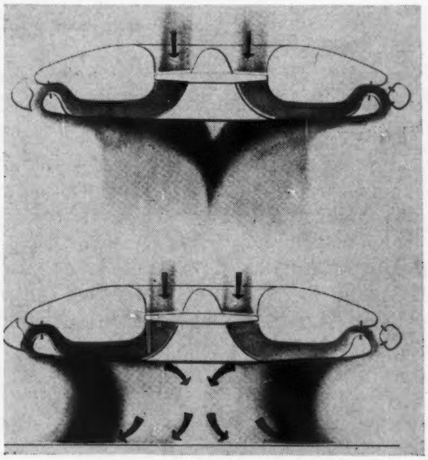


Figure 26
Air flow diagram — hovering

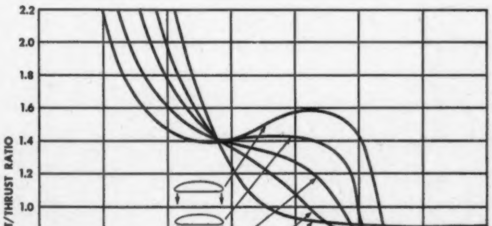


Figure 27
Idealized effect of jet efflux angle on lift/thrust ratio

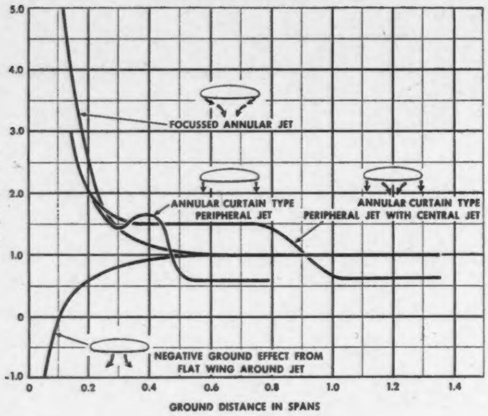


Figure 28
Ground cushion effects with annular curtain, central and focussed jets

which the jet leaves the lower surface of the vehicle. It will be noticed how the hump in the curve gradually disappears with progressive focussing; it is important to mention that this hump is associated more with the thinner peripheral jets. If relatively thick jet curtains are used the hump will be found to disappear as the jet is thickened.

Figure 28 is a summary curve showing the four basic forms, focussed, unfocussed, the plain central jet, and a combination of the last two.

The critical height on the Avrocar was the cause of considerable dynamic instability even though static stability was measured on the balance, and the explanation of this is as follows. Consider the vehicle to be just above the critical height with its jet focussed and attached to the lower surface, and that the vehicle is then disturbed causing one side to fall while the other side rises; on the falling side the jet jumps out becoming unfocussed, while the rising side stays above the critical height and remains focussed. This flow change on the low side will move the center of pressure towards that side, which is in the stable direction, tending to tilt the vehicle back again to the level position (Figure 29).

Unfortunately this flow change is associated with a considerable hysteresis; the jet becomes detached at some angle of deflection but does not attach again until the vehicle has tipped well past the angle at

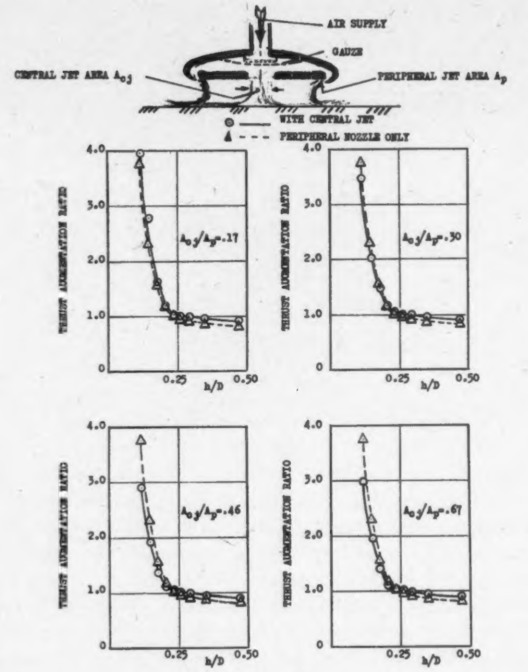


Figure 30
Effect of central jet on lift augmentation

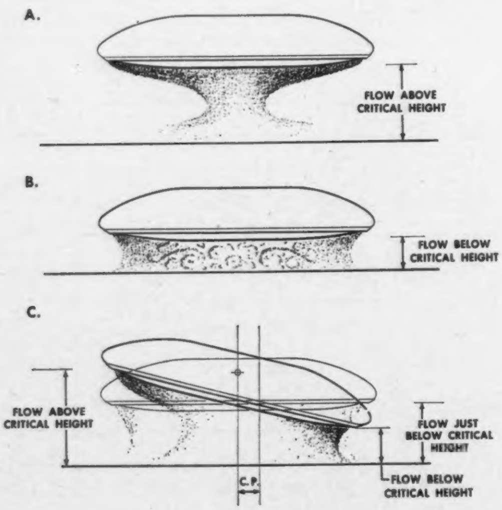


Figure 29
Jet flow regimes in area of critical height

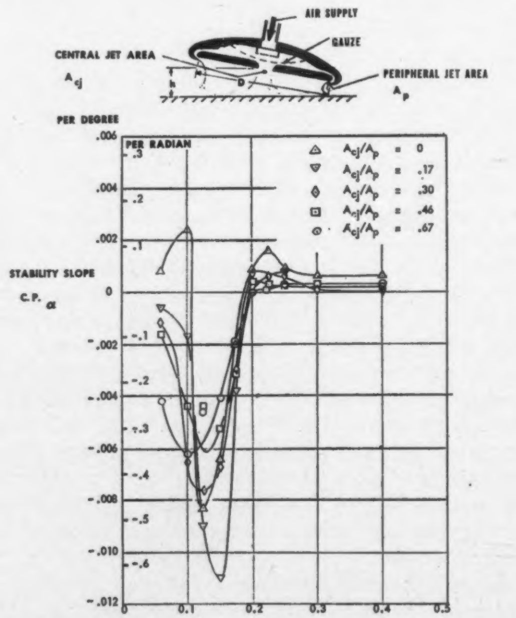


Figure 31
Variation of stability slope with height above ground and central jet strength

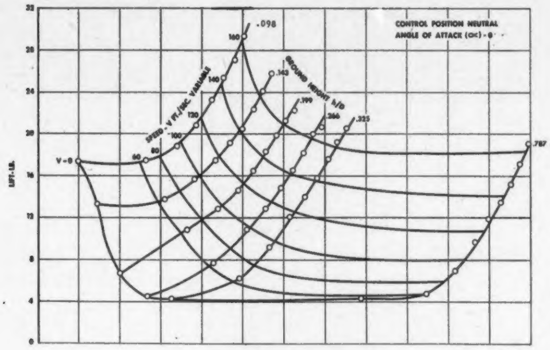


Figure 32
Lift vs forward speed and height above ground*

which it became detached, so causing an overshoot in the other direction, making the opposite side become separated. This will cause a divergent motoring action.

On the Avrocar, the situation was eventually cured by increasing the strength of the central jet, and also increasing the sensitivity of the aircraft stabilizing system. Having decided to use a central jet of one form or another to stabilize the cushion, we were naturally interested to know the efficiency of this process and what loss of potential lift was being incurred by using it. We went to some trouble in this respect, employing a 1/20th scale model of the Avrocar with a central jet which could be varied in strength and size with respect to the peripheral jet. Some of the results of this investigation are shown in the curves of Figures 30 and 31. This investigation was carried out during a study contract on various facets of the

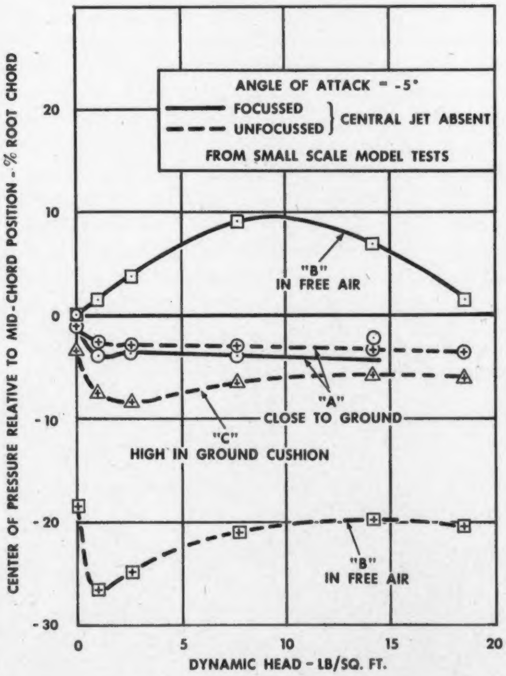


Figure 33
Effect of focussed annular jet on center of pressure location

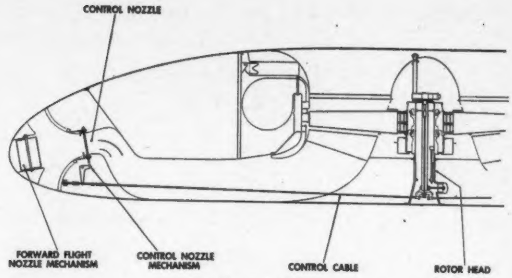


Figure 34
Control system schematic

Avrocar, funded during the last year by the Canadian Government. It will be seen that except for the very large sizes of central jet the penalty in ground cushion lift is not too serious.

Figures 32 and 33 show the effect of forward speed on lift and pitching moment for a vehicle with a focussed jet of the Avrocar type, and it will be noticed here that, contrary to what I think is the accepted belief, we show that the lift does not fall off but increases with forward speed.

THE AVROCAR STABILIZER

The Avrocar is circular in plan, the engines are evenly disposed, as is the fuel and, to some extent, the two operators; the center of gravity is therefore close to the center of the plan area. The aerodynamic center for a circular planform was found to be 28% of the root chord. The wing will, therefore, have a negative static margin, which follows that it is both statically and dynamically unstable in aerodynamic flight and must be stabilized by artificial means.

We have always mistrusted the use of electronics as a basic part of an essential control system, so to overcome this prejudice it was decided to solve the problem mechanically. This was done in the following manner.

The turborotor was allowed a small degree of freedom (½°) relative to the aircraft structure and a strong spring was arranged to restrict this movement. When the vehicle is pitched or rolled the fan, due to its gyroscopic couples, will absorb some of this freedom against the resistance of the spring. This small movement is then magnified about 20 times by a mechanical linkage depending on a system of flexures, similar to the arrangement used in a wind tunnel balance. The resulting motion is applied to the control system; this in turn directs the peripheral jet to produce corrective pitching or rolling moments from jet reactions at the rim of the vehicle (see Figure 34).

Figure 35 shows an isometric view of the central control post where this mechanical magnification takes place. At the bottom of the picture can be seen an aluminum casting which is part of the vehicle structure on which the main radial ribs terminate. A fixed internal shaft is socketed into this casting carrying a spherical bearing about half-way along its length. Mounted on this spherical bearing and surrounding the fixed central shaft is an outer shaft, which extends upwards past the top of the inner shaft. This outer shaft carries the two main bearings for the fan. Be-

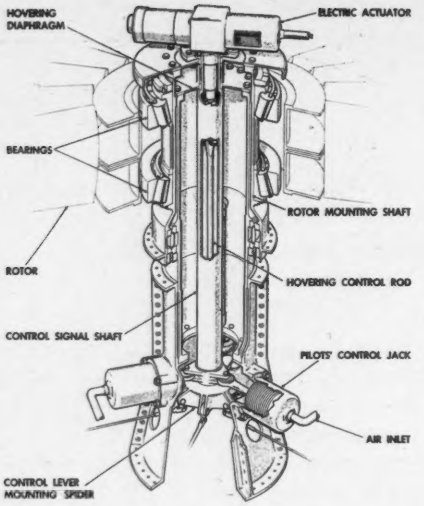


Figure 35
Turborotor shaft assembly

tween the top of these two shafts a gap of 0.04 inches has been allowed so that the top of the outer shaft will move relative to the top of the fixed center shaft about the spherical bearing. At the top of the outer shaft and the fixed center shaft are two diaphragm flexures, so that when the outer shaft moves relative to the center shaft – which it will do if the vehicle is disturbed in pitch or roll due to the gyroscopic couples from the rotor acting through the bearings – the two diaphragms will move laterally relative to each other a maximum of 0.04 inches.

The two diaphragms are joined together by a central control post so that when they move relative to each other the control post is tilted out of the perpendicular. The distance between the diaphragms is 1/20th of the distance from the lower diaphragm to the bottom of the control post. Therefore for a 0.04 inch relative movement of the two diaphragms, the bottom of the control post moves 0.8 inches in any direction, providing enough cable travel to operate the peripheral jet control mechanism and deflect the jet.

Originally the system was arranged so that the control moment would be applied in the same direction as the gyrocouple, at least for steady angular rates. The aircraft thus responded to disturbances as a large gyroscope, without requiring correspondingly large control moments to maneuver.

Analog and digital computer studies showed that the system worked in principle, reducing the effect of input disturbances, but that the resulting motion was poorly damped. The system was redesigned so that the control moment was applied at an angle of 20° to the gyrocouple in order to provide a component of the moment acting in opposition to the rate, i.e. damping. This system was satisfactory for small deviations from steady hovering or forward flight, with sufficient control power. The angle mentioned was denoted the 'rotor phasor angle'. Figure 36 shows three curves in which damping is plotted against the spring stiffness of the system. The curves represent boundaries between a stable and an unstable situation; everything

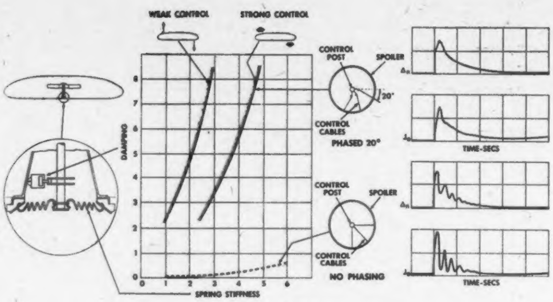


Figure 36
Gyro-stabilizer

to the right hand side of a curve is stable and to the left unstable. The two top curves represent two control systems of different strengths with 20° phasing, and the lower curve represents a system with no phasing. It will be seen how very little area exists to the right hand side of the lower curve. The plots on the right hand side of Figure 36 indicate the time the control system and the vertical accelerations on the vehicle take to damp out after an input disturbance. It will be seen that with 20° of phasing the damping is quite satisfactory; however, with no phasing at all it becomes very oscillatory.

Difficulties with this system were twofold. First, control power was considerably less than planned for initially, and the angular amplitudes of the precessional oscillations, characteristic of the gyroscope, were objectionable. Second, the directions of control input required for maneuver and for trim about any one axis were substantially different (approximately 90° in the original system and 70° in the damped system). Attempted maneuvers on a flight simulator which allowed large pitch angles and unlimited roll angles quickly showed the undesirability of such an arrangement. The system was then redesigned so that the control moment was applied at an angle of 95° to the gyrocouple. The component at 90° provided strong damping, while the remaining component was intended to cancel the gyrocouple, thus eliminating precessional oscillations (the 'cancelled gyro' system). Stick motions for maneuver and trim about any axis were then substantially the same. The actual angle required to cancel the gyrocouple depends on the overall system gain (control moment/aircraft rate), which varies with aircraft configuration and engine speed. 95° was selected as a suitable compromise.

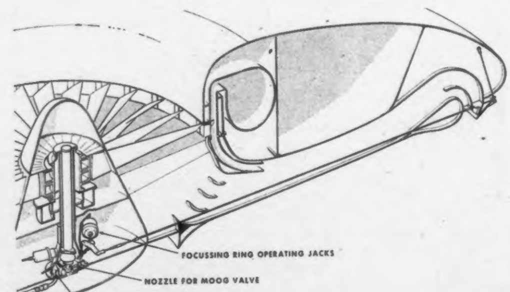


Figure 37
Section through Avrocar showing powered focussing control

CONTROL SYSTEM

The mechanical control of the jet was originally achieved by spoilers (Figure 34) forming a double ring around the periphery and projecting slightly from the sides of the radial duct. Outboard of the spoilers the duct was bifurcated with constant radius walls, to which the jet tended to adhere by the Coanda effect. Motion of the spoiler ring up or down resulted in corresponding deflection of the jet. The ring was connected to the rotor so that deflection of the rotor resulted in an angular deflection of the ring about the appropriate axis, producing the required control moment. The ring could also be raised or lowered, by means of an electric actuator, to provide control of the jet lift in hovering and low speed flight (the 'jet trimmer' control). After some development, including the elimination of the upper nozzle and the spoiler in six segments of the periphery, this system produced a good control characteristic with no loss of lift due to control.

In order to improve the hovering lift, the upper nozzle and the spoiler were eliminated completely and control was produced by a ring (Figure 37) at the outboard edge of the nozzle, which was connected to the rotor so that deflection of the rotor resulted in lateral deflection of the ring. This 'focussing ring' caused the jet to focus beneath the aircraft and to flow downward as a solid tree trunk of jet, as explained earlier.

This type of control was tested on a 1/20th scale model of the Avrocar and was found to possess two properties; as well as moving the center of lift it also altered the direction in which the jet vector left the vehicle (Figure 38).

On the model it was found possible, by moving the control ring its full amount rearwards, to deflect the total jet 45° and so realize 70% of the momentum thrust in the forward direction.

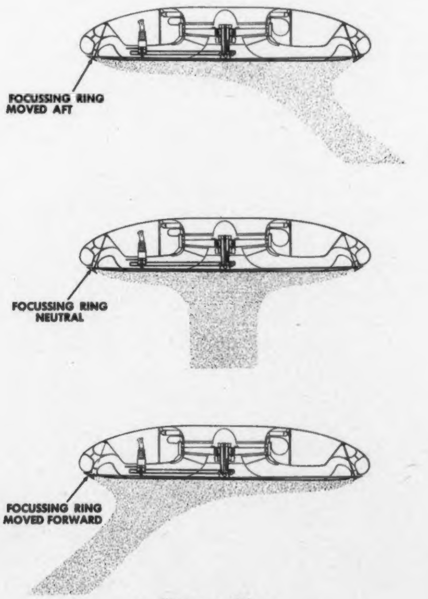


Figure 38
Focussing ring control positions

To obtain the full performance we had estimated, it would be necessary to find a method to deflect the jet all the way backwards and recover 90% to 95% of the gross thrust. We were, however, attracted by the simplicity of this focussing control. It seemed from our tests that enough thrust would already be available to make a transition from the ground cushion to aerodynamic flight and, since our contracts up to this period had all been fixed price, we were anxious to demonstrate this as early as possible without further redesign to the vehicle.

When the control ring is moved aft, a nose-down pitching moment is realized as well as a forward acceleration. This turned out to be a satisfactory state of affairs. Wind tunnel measurements indicated a strong nose-up pitching moment due to intake conditions with forward speed. As speed is increased so would be the nose-up pitching moment and to trim this the ring would be pulled further aft causing the center of jet reaction to move aft with a resulting nose-down moment; at the same time the jet is deflected rearwards, increasing the thrust. Provided this arrangement is sufficiently powerful, the 1/20th scale model indicated that thrust and pitching moments could be handled together and that transition would be possible (Figure 39).

Figure 39
Transition flight path

A good deal of development produced a system with good control characteristics and improved lift, but with large aerodynamic forces on the ring due to the jet flow. Consequently, the rotor was connected to the ring through a pneumatic system involving Moog valves at the rotor shaft and bellows connected to the ring. This power control system (Figure 37) turned out to be very satisfactory.

It was arranged so that the pilot could apply control in pitch and roll through Moog valves on the control stick and bellows connected to the rotor control post. For maneuvering the system is ideally oriented in such a way that the pilot, in displacing the stick, applies the resultant of the following three moments to the rotor: a moment to supply the gyrocouple required for the desired angular rate, so that no unwanted control is applied by the rotor; a moment to deflect the controls sufficiently to supply the gyrocouple to the aircraft; and a moment to deflect the controls sufficiently to counteract natural damping. Since the first is generally the largest, all systems to date have incorporated a 90° change in direction (or 'pilot phasor angle') between the stick motion and the bellows force. For trim changes, however, the system

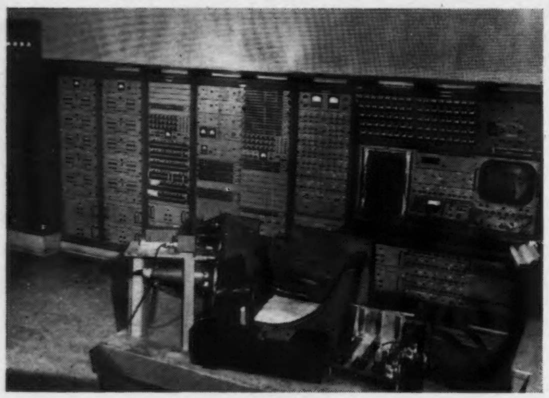


Figure 40
Avrocar flight simulator

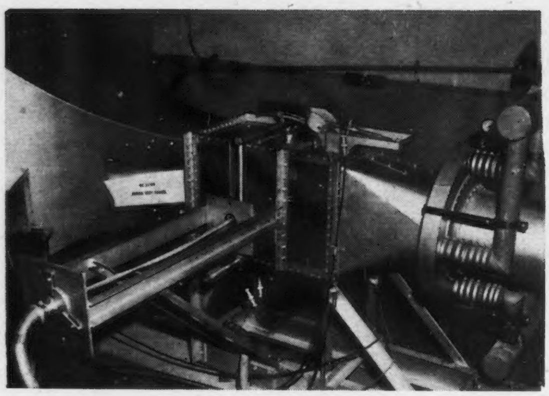


Figure 42
Avro 18 inch × 18 inch ejector wind tunnel

should be oriented so that statically the control moments applied would be in the normal sense, i.e. nose-up pitching moment for stick back etc.

Yaw control is applied by a twist grip on the stick driving Moog valves. The pressure is fed to jacks which operate vanes in the duct at the wing tips.

The Moog valve is a device which transforms small mechanical displacements into pressure signals. A nozzle supplied with compressed air (in this case, primary engine compressor bleed air) faces a plate which is connected to the moving elements. Upstream of the nozzle is an orifice, and between the orifice and the nozzle a tapping yields a pressure which is a function of the supply pressure and the gap between the nozzle and the plate.

Previous studies of the spoiler control system using analog and digital computer techniques showed the characteristics of the system in hovering flight, and in forward flight at two speeds (100 and 265 kts). In view of the negative static margins, a simple flight simulator was rigged using a small control stick and an oscilloscope display of pitch, roll and sideslip angles (Figure 40). The analog was flown by several pilots

Figure 41
Avrocar 1/20th scale model

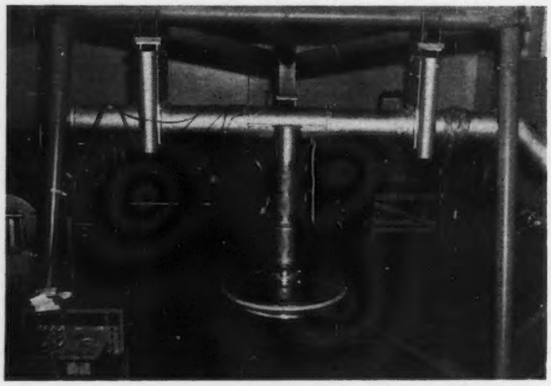


Figure 43
Avrocar 1/5th scale model

with various simulated aircraft and control system configurations in all three flight conditions. A height display and a height control were added for hovering, the latter being a lever simulating the throttle and a switch for the jet trimmer control.

The other test facilities and models used during the development of the Avrocar are shown in Figures 41, 42, 43, 44 and 45. These include the 1/20th scale model of the Avrocar (Figure 41) which was tested in the 18 inch × 18 inch ejector wind tunnel at Malton (Figure 42).

The 1/20th scale model was designed using an air ejector buried inside the wing. The primary air flow to this ejector was supplied at a pressure of 50 to 60 psi down the model mounting post. This was arranged to draw the secondary air flow in through the model intake, and exhaust both primary and secondary flows out through the peripheral nozzle. This model was used a great deal for ground cushion transition and in-flight testing; it suffered from the disadvantage that the intake mass flow was only about three-quarters of the exhaust flow which was quite a difficult situation to correct for. The other model used on the Avrocar was the 1/5th scale model (Figure 43). This was tested in the 20 ft wind tunnel at Dayton. In this model all the mass flow for the jet exhaust was supplied by the downpipe, across the tunnel balance. This resulted in the downpipe becoming very large compared with the model, which made drag measure-

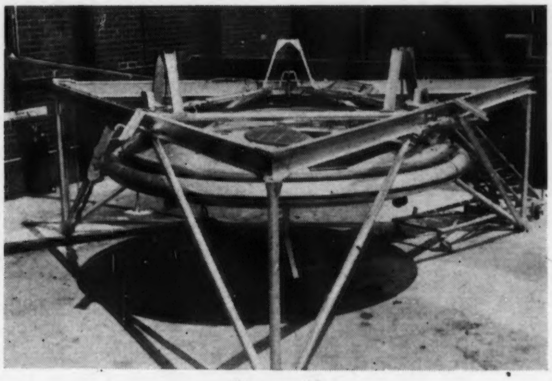


Figure 44
Avrocar test rig

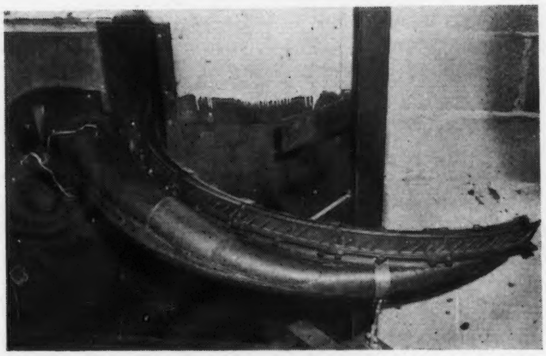


Figure 45
Test rig for Avrocar jet pipe showing fixed nozzle guide vanes

ments difficult to obtain with any degree of accuracy. It was not possible on this model to operate the intake and the jet together.

When the intake suction was applied, the model had to be turned upside down and suction applied to the downpipe; this was useful inasmuch as it provided an opportunity to separate the effects of intake suction from jet exhaust.

The static test rig shown in Figure 44 was built to test out the Avrocar full scale before flying it free. In this rig the vehicle was mounted on strain gauges at different heights above the ground so that lift, thrust and control forces could be measured statically. All controls were operated remotely from an observation room. About 60 hrs of testing was completed on the two vehicles in this rig.

Typical of other test rigs employed is the tusk, or jet pipe exhaust test, Figure 45, which was set up to measure the flow properties of this odd shaped exhaust pipe, using an actual J69-T-9 engine to blow through it.

AVROCAR HOVERING AND WIND TUNNEL TESTING

The contractual arrangement we had with the US Army instructed us to carry out hovering tests on the second Avrocar at Malton to prove feasibility in this area; and full scale tests on the first Avrocar in the 40 × 80 ft wind tunnel at NASA, Ames, to demonstrate, as far as is possible with a static system, the feasibility of aerodynamic flight and also that transition from the ground cushion to free flight is possible, with the trim and thrust forces available. If these three test areas were satisfactory a further contract would be negotiated to cover the second Avrocar during flight test at Malton. Due to the duct losses mentioned earlier, we did not have enough thrust to hover out of ground effect. The hovering tests were therefore limited to hovering within the ground cushion. These, after considerable control development, were carried out satisfactorily up to speeds of 35 mph.

The first attempt at proving in-flight capability with the Avrocar in the 40 × 80 ft wind tunnel at Ames was not satisfactory. On the full scale aircraft it became apparent that the focussing control did not deflect the jet as far aft as the model indicated it would. This resulted in insufficient thrust being available for transition and, as a further result, insufficient thrust to trim out the powerful nose-up moment produced by the intake.

We were therefore instructed to modify the Avrocar control system to put this right and were given a further contract to enable us to do so. The modification we proposed involved leaving the focussing ring alone, since it had proved to be a very effective hovering control, and providing a further outlet for the jet at the rear and sides of the Avrocar. This outlet would be controlled by a transition door which would direct the air past the focussing ring for hovering or, alternatively, allow it to escape generally rearwards past a control vane positioned at the outlet of this duct to deflect the jet to provide pitch or roll control during forward flight (Figures 46 and 47).

It was found as a result of small scale wind tunnel tests that blowing the jet exhaust rearwards from the back of the vehicle, and sideways and rearwards from

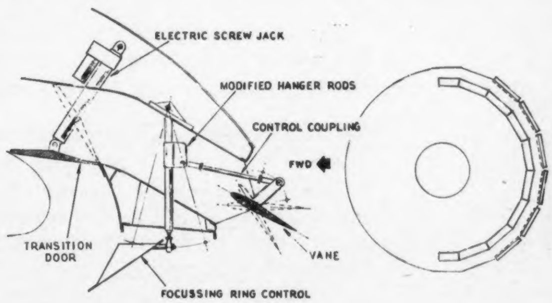


Figure 46
Modification to rear of Avrocar

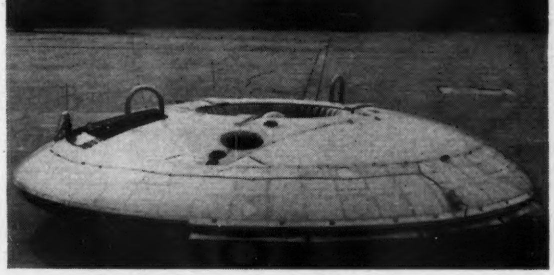


Figure 47
Avrocar showing modification to rear end

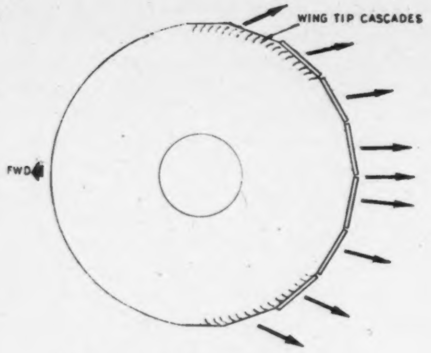


Figure 48
Jet flow in forward flight

the sides, resulted in the fan shaped deployment of the jet (see Figure 48), producing beneficial effects which brought the aerodynamic center back with respect to the center chord of the wing, and increased the lift curve slope from 1.8 to 3, as though the aspect ratio had been artificially increased.

The first unsuccessful tests were carried out at NASA, Ames, in April 1960. A further series, including the above modifications, have just been completed in April 1961. The results of these later tests, which have not been fully reduced, making due allowance for the reduced thrust level still present in the vehicle, appear to be satisfactory and establish that both transition with the Avrocar and aerodynamic flight are possible.

The next stage is to proceed with the flight testing of the vehicle, our objective for the last three years.

ACKNOWLEDGMENTS

The development of the annular jet in Canada has been a long process, extending over eight years of hopes and frustrations, with the outcome never really clear-cut.

Those who have had the optimism and tenacity to stay with it have, of necessity, been most stalwart and dedicated, and without their hard work and enthusiasm this development could never have taken place. Particular among these is T. D. Earl, who shared all our ups and downs and whose unceasing efforts and influence contributed largely to keeping us on course. We would like to express our appreciation to the Management of Avro for their encouragement, understanding and unfailing support.

And further, we would wish to express our thanks to all those who offered their support and enthusiasm from the sidelines; this has often contributed more to keeping us going than anything else.

McCURDY AWARD

The McCurdy Award will be presented at the Annual General Meeting, which will be held on the 14th and 15th June, 1962.

It is the premier award of the Institute and is presented annually

For outstanding achievement in the art, science and engineering relating to aeronautics.

The recipient shall be a person who, while a resident of Canada during recent years, has made a significant personal contribution in any field of endeavour, including, but not limited to, engineering, science, manufacturing, aircraft operations or management.

NOMINATIONS ARE INVITED

Each nomination should include

(a) The name and affiliation of the nominee,
(b) A citation of the particular achievement for which the nomination is being put forward,
(c) Confirmation that the nominee was a resident of Canada at the time of the achievement, and
(d) The name of the nominator.

The nominee need not be a member of the C.A.I.

Nominations should be in the hands of the Secretary not later than the 31st October, on which date they will be handed over to the Senior Awards Committee.

ANALOG, DIGITAL AND HYBRID COMPUTERS†

by Dr. D. C. Baxter*, M.C.A.I.

National Research Council

SUMMARY

A general comparison of the operating characteristics of electronic analog and digital computers has been given. Three proposals for the inextricable mixing of these two techniques have been reviewed and the proven applicability of a looser coupling of independent analog and digital computers has been outlined. The coupling system which will combine the National Research Council's Analysis Section's computers has been described.

INTRODUCTION

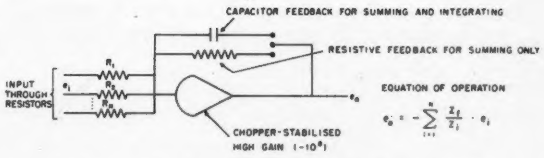
Electronic analog and digital computers are being increasingly used in science and engineering. Interest is also growing in less conventional computation methods, especially the hybrid combination of these two types. The Mechanical Engineering Division and the National Aeronautical Establishment have used both analog and digital computers for several years and, in addition, the two machines in the Analysis Section have been recently coupled together.

This article will review the distinguishing characteristics of analog and digital machines, compare their capabilities and limitations, and then consider the mating of the two into a single operating unit. In the last case, both the coupling of general-purpose machines (as in the Analysis Section) and a more intimate combination of the two techniques are treated.

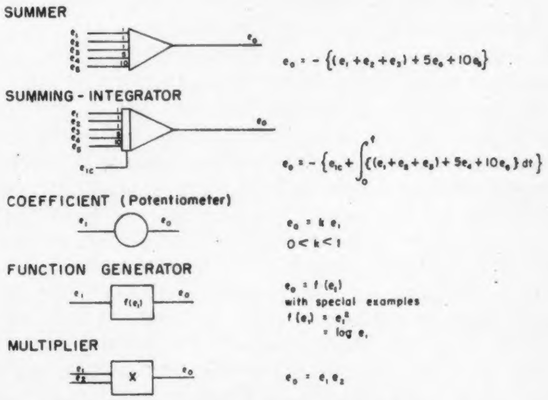
DEFINITIONS

Any "computer" is a system which can manipulate quantities of information. In the electronic analog computer the information to be processed is handled internally in the form of time-varying, continuous voltages. These voltages can take on any value in a range between say −100 and 100 volts. In the digital computer information is treated in the form of numbers. Auxiliary sensors and converters are necessary first to transcribe information from the outside world (in the form of punched cards, voltages, temperatures, mathematical symbols, bank cheques, heart beats, census returns and so on) into the languages which these two can understand, and second to return answers back again.

Although we say that "numbers" are the internal language in digital computers, in actual fact it is again voltages which are used. A number is represented by a space-time array of voltage pulses. In parallel-word machines the array of pulses representing a number exists on separate wires at the same time. In serial-word machines it exists on a single wire, but is spread out in time as a pulse train. In either case these arrays pass through the computer, one after another.



(a) Basic hardware for operational amplifier



(b) Typical symbolism for components

Figure 1
Basic analog computer operations

MODE OF ORGANIZATION OF ANALOG AND DIGITAL COMPUTERS

An electronic analog computer is built up of a few types of modules, each type being able to perform a specific mathematical operation upon one or more of the voltage signals. The magnitude of the voltage in a wire joining any of the modules corresponds instantaneously to the magnitude of a corresponding physical signal. The most common operations performed by the modules are addition, addition and integration with respect to time, multiplication by a constant, multiplication of two variable and generation of functions (Figure 1). The basic active component is the operational amplifier. It has a high gain (-10^8 typically)

†Paper extracted from the Quarterly Bulletin of the Division of Mechanical Engineering and the National Aeronautical Establishment DME/NAE 1960(4).

*Analysis Section, Division of Mechanical Engineering

Figure 2
Analysis Section's analog computer installation showing the two separate consoles, patchboards, recorders

Figure 3
Analysis Section's digital computer installation showing two magnetic tape units, computer console and typewriter

and uses feed-back techniques to generate sums and/or integrals.

Because of the existence of the integrator, sets of ordinary differential equations are easily treated, and this is the reason for their extensive use as electronic differential analysers or simulators.

A digital computer on the other hand has basic modules which can perform some of the operations of Boolean or logical algebra. The presence or absence of pulses (binary digits 0 or 1) as inputs can activate suitable outputs. The transformation of inputs to outputs takes place only at fixed times separated by the bit time or pulse time. For example, a fundamental unit is the "or" gate which produces a "one" output if either of its two inputs is "one", and a zero otherwise. Modules such as this are combined into an arithmetic unit which can add, subtract, multiply and divide numbers. Other organs of the digital computer will be necessary to move numbers to and from memory; others will be able to interpret numbers stored in memory as instructions to carry out specific operations.

METHODS OF OPERATION

Analog

In the conventional electronic analog computer each operation is performed by a separate component, and all operate simultaneously, so that the computer is a completely parallel processor. Wires are used to connect the computing units, each carrying a voltage signal analogous to one of the physical variables of the problem. Constants needed are entered as potentiometer settings, and initial values are stored on the integrating capacitors. At time zero a switch is thrown and voltages allowed to circulate. Results are plotted as the calculation proceeds. If changes in the interconnection of units can be made easily (as in a patchboard) the computer is called "general purpose", as in the Analysis Section (Figure 2). If the units are more or less permanently connected in one configuration, we have a "special purpose" device.

In this parallel mode, where each operator is in action simultaneously, the only way a larger problem can be treated is to provide more equipment; thus the cost is increased, but the solution time is not.

A reduction in the amount of hardware, at the expense of longer solution time, will be made if some units can be time-shared and used for more than one operation. For example an integrator might alternately form $\int x(t)\,dt$ for one second, and then $\int y(t)\,dt$ for the next second. A memory must now be provided to hold the intermediate answers. Such computers are now becoming available[1, 2, 3].

Digital

In a digital computer it is current practice to provide one central arithmetic unit which can perform both arithmetic and logical operations (test for zero, extract etc). This arithmetic unit must be time-shared by all the operations to be performed; the computer program, or set of instructions to be performed, tells the computer which operations are to use the arithmetic unit next. A memory is needed both to hold this program and all the intermediate answers waiting their turn to use the unit. With the single arithmetic unit, larger problems mean longer running time, as compared with the requirement for more equipment in the parallel analog machine.

As with the analog computer, if the digital computer is designed so that a variety of programs can be handled, it is called "general purpose" (as in the Analysis Section, Figure 3). If restrictions are imposed by more or less permanent fixing of the program it is again "special purpose".

For more description of problem solving on general-purpose computers, and for comparative solution of some problems, see Reference 4.

INCREMENTAL COMPUTER

One such special-purpose digital computer is the incremental computer or digital differential analyser. This differs from the usual digital computer in the way arithmetic is carried out. In the usual or "whole value" computer, numbers of the size of the word length are the only ones treated; i.e. in a 10-digit machine, it is always 10-digit numbers which are transferred to and from memory, or which are added together in the arithmetic unit. On the other hand in the incremental computer only *changes* in numbers are transmitted or added. Usually the allowable change is –1, 0 or 1. This

means a much simpler arithmetic unit and it becomes, in fact, practicable to provide parallel units. This apparent increase in speed and simplicity is partially offset by slowness of logical operations and restriction in range of applicability. For example, the slewing time may be important, i.e. the time to make large changes. This is done all the time in the general-purpose computer of course, but in the incremental machine it can be done only by unit incrementation.

COMPARATIVE SPEEDS

Calculating speed is often a critical consideration in computer applications. For some problems, such as control, it is essential that the computer operate in "real time", that is, the processing speed must match happenings in the physical environment. If you are controlling an aircraft flying at Mach 2, then you cannot ask the aircraft to reduce its speed to Mach 1 simply because your control computer cannot keep pace.

Solution time on an analog computer is limited by the bandwidth of the components used. This varies from about 10,000 cps for purely electronic components to 1 cps for servo-multipliers. This means that operations can be performed satisfactorily on voltages which are varying as rapidly as these frequencies indicate.

Digital computer speed is usually described in terms of the time required for a given operation. For example the time to add two numbers (in a "whole value" machine) varies from 1 millisecond in a typical serial-word magnetic-drum-memory machine to 2 microseconds in the latest parallel-word core machines. The time for a decision command is about the same, while the longest time would be a multiply or divide operation which may be several times longer than an add time.

In order to relate digital and analog operating speeds, consider the digital operating on a real-time problem. For any form of continuous signal to be analysed in a digital computer it must be sampled at intervals, usually some fixed time interval, Δt, apart. If $\Delta t < 0.1/f$ then a signal of bandwidth f cps is completely described. (Actually the Shannon sampling theorem only requires two samples per cycle in principle, instead of the 10 assumed here.) The digital computer must take these samples, compute with them, and return answers to the environment in a time no greater than Δt. Suppose the calculation involved one hundred steps, or between 200 microseconds and 100 milliseconds depending on the computer. Thus the allowable bandwidth, $f = 0.1/\Delta t$, would be between 1 and 500 cps compared with between 1 and 10,000 cps for the analog. It is important to note, though, that any speed comparison depends on the problem to be solved.

PRECISION CHARACTERISTICS

The precision of a signal is the degree of exactness with which it is stated, or commonly the number of digits with which the signal is represented. (This is to be distinguished from the accuracy which is the overall freedom from error.) In the digital case the precision is determined by the word length, the number of digits used to denote each number, and is essentially unlimited. In practice, however, word lengths of between three and twenty decimal digits are used, so that the precision is between one part in 10^3 and one in 10^{20}. Such high precisions are possible because of the large tolerance to voltage level when only the presence or absence of a pulse is to be recognized.

In the analog case precision is limited by the noise level in electronic components and by design tolerances in electrical and mechanical parts. Modules will have a typical precision of from one part in 10^2 to one in 10^4.

RELATIVE EASE OF USE

Consider the question of comparative ease of use of general-purpose analog and digital computers. This will in turn lead to aspects of number representation.

The question of ease of communication between the problem originator and the computer is an important one. Digital computers have a greater capacity for logical processes than analogs. This ability allows them to translate from a program written in a language suitable for human comprehension, such as algebra, into a computer-oriented language. Eventually problems will be describable in some universal language, for translation by the particular computer into its own language.

The digital programmer can readily incorporate previously-written and checked-out programs or subroutines; the appropriate set of cards is simply inserted into the programmer's own set. An extensive library of subroutines accumulates, becoming a valuable part of any installation. For the analog operator the corresponding tools are special-purpose devices such as resolvers or fixed-function generators of special subcircuits such as sine-wave generators, hysteresis loops and so on.

In order to have large digital computers operating efficiently, wasted time between problems must be kept to a minimum. For this reason supervisory programs have been written which arrange that once the computer is finished with one problem the next one is called in and set up automatically. It is not unusual in large computers to have problems changed every few minutes.

On the other hand, the operator of the analog machine is more often the problem originator than in the digital case, and is in closer physical contact with the problem as it is running. Answers are plotted continuously in front of him. Each voltage in his simulation has meaning in terms of his physical problem and parameters are easily adjusted. In real-time operations actual hardware from the physical world can be readily introduced.

One of the troublesome jobs of an analog computer programmer is scaling. The computer must be designed for operation within some specific voltage range, say ±100 volts. On the other hand, any voltage less than, say 0.01 volt, lies below the precision of the computer. Thus all signal voltages must be made to lie within this dynamic range of 0.01 to 100 volts, i.e. 4 decimal digits, and in particular the art of scaling lies in ensuring that the maximum value of each signal

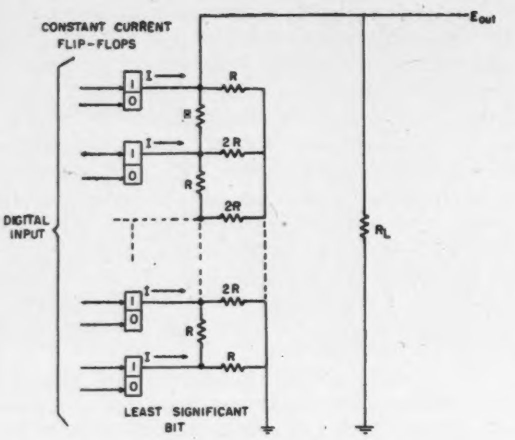


Figure 4
Current summation digital-to-voltage conversion[6]

shall reach as close to the 100-volt maximum as possible, sometime during the given solution. When the input numbers in a problem vary over a wide range it becomes difficult to maintain this ideal situation.

On a digital machine, as already described, the possible operating range for numbers can be, and is, larger – a typical word length being 10 decimal digits. In "fixed point" operation all numbers are treated by the machine as if there were a decimal point in some unchanging position somewhere in the 10 digits, say at the extreme left-hand end. Thus the allowable range for numbers is from 0.0000000001 to 0.9999999999. In digital calculations the range of variable values required is often even larger than this, and for complex problems the scaling of all intermediate values to conform to these limits is tedious, time-consuming and subject to errors. Thus, digital computers commonly make use of "floating point" operations, which allow numbers to be represented in such a large range (e.g. 10^{-38} to 10^{+38}) that the scaling problem is essentially eliminated. This is done by dividing the number into two parts, an exponent and a mantissa. Operations are then carried out on these pairs of numbers, either by subroutine or by hardware. For example, adding two numbers requires comparing exponents, shifting the mantissa with the smaller exponent and then adding the mantissas. The logic so required is beyond the capabilities of conventional analog devices.

Two time-consuming parts of an analog computer set-up are wiring and potentiometer setting. However, the former can usually be done away from the computer. A digital technique incorporated in new analog machines is that of servo-setting potentiometers with readings taken from punched paper tapes or cards. Also the use of "servoset" or prepackaged diode-function generators materially reduces set-up time.

Often the parameters in a problem are to be reset according to the results of a previous run, as in the iterative solution of eigenvalue and integral equations[4]. To do this automatically and thus exploit the analog computer's high operating speed, schemes using logical circuitry are described in References 1 and 5.

A-D AND D-A CONVERTERS

It is appropriate here to say something of the mechanics of typical analog-to-digital (A-D) and digital-to-analog (D-A) converters.

A common D-A converter involves the input of constant current sources into a resistance network as shown in Figure 4. Flip flops are used to deliver 0 current when their input bit is a "zero", and some fixed current I when the input is a "one". The currents are introduced into the net at a point such that the appropriate weighting $(1/2^n)$ is achieved. It can be shown[6] that the output voltage, E_{out}, of this converter is given by

$$E_{out} = \frac{IR}{3}\left[\frac{R_L}{R_L + 3R/2}\right]\frac{N}{2^{n-2}}$$

where n is the number of bits in the binary number N $(0 \leq N \leq 2^n - 1)$.

On the other hand, an A-D converter is typically of the comparison type shown in Figure 5. Here the digital output is fed back through a D-A converter and compared to the analog input voltage. The difference is used to insert bits of decreasing weight into the output until a balance is reached. For n bits in the output, $2^n - 1$ steps are required to cover the entire range.

Note that the A-D case is considerably more complex than the D-A one because switching and comparison circuits are needed in addition to a D-A converter itself. Also, an instantaneous conversion is not achieved since a sequence of steps are required. Typically 4 microseconds per bit of output are needed for conversion.

HYBRID COMPUTER

We have seen that an electronic analog computer deals with continuous voltage signals which are analogs to the quantities of the problem. Units have been evolved which operate on these at high speed, usually in parallel, and with moderate precision. Digital computers deal with numbers coded as pulsed voltage arrays and can perform complex logical operations using one arithmetic unit operating sequentially on numbers previously stored in a memory. The result is moderate speed of problem solution. Are there problems where these characteristics can be profitably combined?

Looking at the question of precision, can we devise computers in which part of the information about each quantity is held in digital form and part as an analog voltage? Skramstad[7], is constructing components for a computer of this type, where the three most

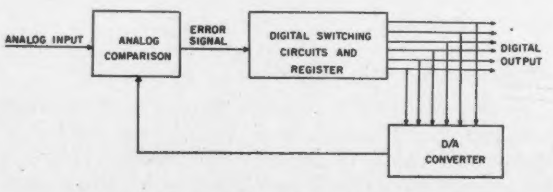


Figure 5
Comparison method for analog-to-digital conversion[6]

significant digits of all quantities are held in digital form and the remainder in the conventional analog way. Thus the analog precision is increased one-thousand fold. As an example, consider the hybrid multiplier. If $x = x_d + x_a$ and $y = y_d + y_a$ are two variables with digital and analog parts (subscripts d and a), then their product is

$$\begin{aligned} xy &= (x_d + x_a)(y_d + y_a) \\ &= x_d y_d + x_d y_a + x_a y_d \end{aligned}$$

where the term $x_a y_a$ is negligible. Skramstad finds this requires three digital registers, three digital-to-analog converters, an analog summer and a comparator unit.

Another proposed computer for real-time flight simulation proposes time-shared analog circuitry using a program from a digital memory[8]. Another novel feature is the use of a floating point form for number representations, with the exponent held in digital form and the mantissa as an analog voltage. Digital circuitry provides the logical ability necessary to perform the exponent operations, shifting and normalizing in the floating point arithmetic. A prototype has been built using the time-sharing features and the floating point techniques, but without the digital memory[9].

Birkel proposes using analog-to-digital (A-D) and digital-to-analog (D-A) converters themselves as hybrid computing elements in sampled data or process control applications[10]. These are present for raw data conversions already and can be time-shared so that little cost is added. If the reference (analog) voltage of a D-A converter is made one variable, its product with a digital input becomes the analog output. Thus we have an analog-digital multiplier. An A-D converter provides a digital answer for the ratio of an analog input to an analog reference; hence is a divider. Reference 10 shows how these can be combined into more elaborate circuits to compute such things as square roots and statistical parameters. Birkel again proposes digital logic to provide floating point features, but further will do adding and subtracting of mantissas by digital processes.

These have been three examples of an intimate intermingling of analog and digital circuits. Each is more complicated than the use of either type of computer alone, and since none has as yet been carried through to completion an economic advantage has not been established.

COUPLED ANALOG AND DIGITAL COMPUTERS

Although the case for a true hybrid is not yet proven, there is considerable experience to commend a looser coupling for special purposes. Here complete analog and digital computers operate simultaneously on a problem, each being capable of some degree of independent action. The coupling unit must provide two-way conversion between analog and digital signals, compatible in speed, timing, accuracy and format.

Some cases are those in which special-purpose digital compters are used as auxiliaries to an otherwise analog system:

(a) Function Generation – One of the most difficult tasks for a truly analog device is the generation of arbitrary functions of more than two variables. A general-purpose digital computer can be used for this purpose, and special-purpose digital function generators are now commercially available for direct connection to analog computers[11].

(b) Pure Time Delay – The common method of analog generation of time delay (transport delay) has been the use of a magnetic-tape unit with two displaced heads or by various approximating polynomials. However these are not convenient to adjust and cannot be varied under control of the computer itself. On the other hand, a general-purpose digital machine or a magnetic-drum digital device now available commercially can provide flexible, accurate and variable delay.

Other workers have used the two computers for simulation or control:

(i) Simulation of digitally controlled aircraft guidance systems, chemical processes, and machine tools. During the development and design stages, the digital computer simulates the digital-computer controller, while the analog simulates the physical system.

(ii) Complex real-time system simulations, particularly when high-frequency signal content makes the required sampling interval too short for an all-digital simulation. Analog computation of those parts in which high frequencies are involved may be possible, reserving the digital computer for those parts requiring high accuracy[12, 13, 14, 15]. This same division of labour can be advantageous in a control computer of the combined type.

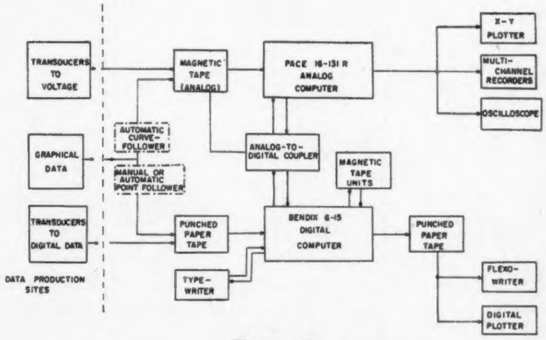


Figure 6
Analysis Section's computation facilities

COUPLING OF THE ANALYSIS SECTION'S COMPUTERS

The general-purpose analog and digital computers in the Analysis Section (Figures 2 and 3) are to be coupled by a linkage system of A-D and D-A converters. Figure 6 shows the resulting facilities. The coupling unit will provide for sampling of eight analog voltages and transferring them to the digital computer where computations are performed. Eight digital answers are then converted and presented back to the analog computer. The sampling and presentation of the analog voltages is done simultaneously on all channels and the conversion and transfer time in either direction is 2.2 milliseconds. The size of word transferred will be 13 binary digits. Samples are taken and results returned to the analog by a digital computer command. This control may be slaved to an external clock so that transfers occur at fixed time intervals of between 0.05 and 10 seconds.

Such a general-purpose combined system will be new in Canada, but several do already exist elsewhere (References 13 and 15 for example). It will be used initially for (i) function generation and time delay on the analog computer, (ii) as a flexible input-output device for either computer, and (iii) in research into various aspects of computer control, such as optimizing techniques and effect of computation-introduced time delays on system stability.

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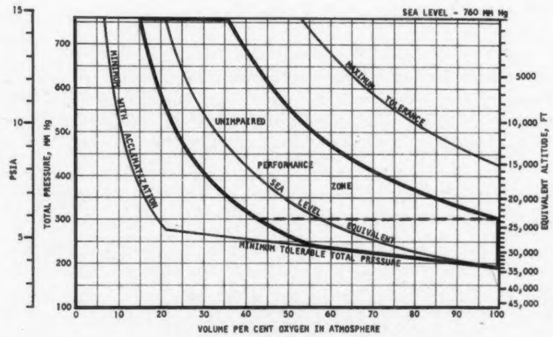
TECHNICAL FORUM

PHYSIOLOGICAL PERFORMANCE CHARTS

(In the last issue reference was made to some Physiological Performance Charts prepared by the Garrett Corporation's AiResearch Manufacturing Division of Los Angeles. These had been brought to our attention by Garrett Manufacturing Ltd. of Toronto. The following is an explanatory note recently received.)



Oxygen-Pressure Effects

THE information, presented in two graphs, reflects the latest results of tests and research in the environmental control field.

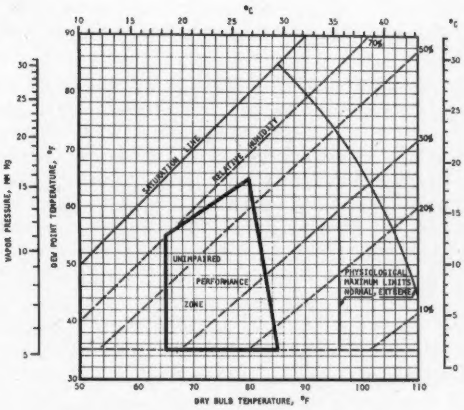
One graph – an oxygen-pressure chart – shows the physiological effects of oxygen in the atmosphere of a space vehicle and the total pressure of that atmosphere.

The other – a temperature-humidity chart – presents the physiological effects of dry bulb temperature and the humidity of the atmosphere in a space vehicle.

The oxygen pressure chart shows three main areas of physiological performance: a minimum acclimatization zone; an unimpaired performance zone; and a maximum tolerance zone.

The unimpaired performance zone indicates the range that can be tolerated without performance decrement. This range is similar to atmospheric air at sea level, containing 21% oxygen by volume and leading to a blood saturation of 95%. To maintain the same degree of oxygen in the blood at lower pressures, the percentage of oxygen in the atmosphere must increase as shown in the chart.

The minimum zone is based on the effective partial pressure of oxygen, disregarding aeroembolism which may occur below 300 mm Hg total pressure in the absence of adequate denitrogenation. This aeroembolism limitation is indicated by the interrupted horizontal line on the chart.



Temperature-Humidity Effects

The maximum tolerance zone requires acclimatization. Acclimatization is considered to be a continuous exposure to conditions of successively lower pressure, with no intermediate return to higher pressure.

The second graph – temperature humidity chart – describes an unimpaired performance zone commonly referred to as a "shirt-sleeve" atmosphere.

As shown on the chart, the limits of this zone are (1) a dew point of 35°F, below which excessive drying of the respiratory system takes place, (2) a relative humidity of about 70%, above which skin and clothes are uncomfortable, (3) a dry bulb temperature of 65°F below which extra clothing is required, (4) a dry bulb temperature of 80° to 85°F, depending upon dew point.

As shown in the chart at points to the right of the unimpaired performance zone, appreciable perspiration will occur as the body seeks to maintain a heat balance. At the normal limit, the perspiration rate will be 1 pint/hr; at the extreme limit, to which many individuals are unable to adjust, the perspiration rate will reach 1 quart/hr.

The Physiological Performance Charts were developed by F. H. Green, AiResearch Assistant Chief of Preliminary Design, in cooperation with Dr. James Waggoner, Garrett's Aerospace Medical Director, and Dr. Ulrich Luft, Lovelace Foundation.

BOOKS

Inertial Guidance, by C. S. Draper, W. Wrigley and J. Hovorka, Pergamon Press, New York, 1960. 130 pages. Illus. $6.50.

The cloak of security that has surrounded developments in the area of inertial navigation has prevented very much formal literature on the subject to be published until recently. Even though the field is more than fifteen years old, this book is one of the first unified treatments on inertial guidance to appear as an unclassified publication.

The book opens with a general discussion of guidance, leading to a qualitative description of a typical inertial navigation system. A brief historical summary follows, tracing some of the techniques back to very early developments in aircraft and marine instruments, and indicating many of the present applications in current weapons in the USA.

The basic principles of inertial guidance are developed from the standpoint of the components and hardware used to make up typical guidance systems. A digression is then made to describe the role of fields in navigation, wherein the earth's gravity field is described in some detail. The actual mechanization of a more specific inertial navigation system is then presented which leads to a quantitative description of Schuler tuning, and its application to both an undamped and a damped vertical indicator.

A relatively detailed treatment is given to the problems of geometrical stabilization, with emphasis on the integrating single degree-of-freedom gyro and its use in a single axis base motion isolation system. A rather protracted description of the problem of testing integrating gyros is included. Finally, a very brief chapter is devoted to the applications of inertial techniques in areas other than guidance and navigation.

With one or two exceptions, the material is arranged well. Equations and mathematical derivations are developed in "Summaries" which are separated from the main text, thus improving the flow of ideas for fast reading. The description of the very important five gimbal system appearing in Chapter 3 is somewhat brief for the uninitiated, and an expanded version appearing in Chapter 5 would be a definite improvement. Also, the material in Chapter 7 dealing with base motion isolation drives using integrating gyros should appear prior to Chapter 6, for this would aid in crystallizing the notions concerning space integration and its application within a practical Schuler loop.

The authors were undoubtedly still plagued with security restrictions; nevertheless, the material content covers a surprisingly large area of the subject. In general, the concepts and notions are explained adequately for someone who is or has been ensconced in this or related fields. The writing is directed at graduate-level engineering scientists, and a thorough grounding in navigation concepts and Newtonian physics is assumed on the part of the reader. It is felt that a more expansive treatment of the fundamental concepts would be highly desirable for the average reader.

The section on the testing of gyro units appearing in Chapter 7 is a very important one to include in this book. Unfortunately, the detail included in this section is not in keeping with the less detailed coverage of other equally important subjects. Furthermore, the description is incomplete in that it does not clearly reveal how the final adjustments are carried out, or how the final data is presented. The inclusion of the results of an actual gyro test would have been most useful for this purpose.

It is unfortunate that the Chapter on the application of inertial techniques is so limited. The many unclassified (and non-military) applications referred to so briefly in this Chapter would have made excellent material to draw upon for examples, and would be of very wide general interest.

The notation utilized in the "Derivation Summaries" is typically of the M.I.T. Instrumentation Laboratory variety, and is generally annoying and cumbersome to persons not trained in the Draperian School. Finally, the reference to non-existent figures in Figures 7-8, 7-11 and 7-12 as well as Table 7-2, indicates that at least part of the book is extracted from other reports and represents a somewhat poor job of editing.

In spite of the few shortcomings described above, I would not hesitate in recommending "Inertial Guidance" as a good reference and tutorial work on the subject.

Dr. P. A. Lapp

Handbook of Supersonic Aerodynamics: Section 18, Shock Tubes, by I. I. Glass and J. G. Hall. Navorad Report 1488 (Vol. 6), US Government Printing Office, Washington, D.C., 1959. 642 pages. Illus. $3.75.

This volume is an extension of the well known Handbook of Supersonic Aerodynamics series; it contains 642 pages and an extensive bibliography.

As pointed out by the authors, the shock tube was first used in France by Paul Vielle in 1899. Little further application of the shock tube was made until 1940 when Payman and Shepherd in the United Kingdom used it as a research tool. Since that time its use has increased enormously and it has found application in many fields, such as the study of shock and rarefaction waves and their interaction, combustion and flame propagation, magnetogasdynamics, aerodynamic test facility in the subsonic, transonic and supersonic flow regions and as a means of driving hypersonic shock tunnels. Consequently, such a sizeable topical literature has accumulated that a comprehensive account of shock tube theory and application is most welcome.

The volume is subdivided as follows:

(1) Introduction.
(2) Performance of simple, constant-area shock tubes.
(3) Observed flows in a constant-area shock tube.
(4) Production of strong shock waves by various modifications to the simple shock tube.
(5) Applications of the shock tube.
(6) Shock tube materials, design and construction.
(7) Shock tube flow measurements and instrumentation.

The teaching experience of the authors, both of whom are associated with the Institute of Aerophysics at the University of Toronto, has evidently contributed considerably to the systematic layout of the text.

This applies in particular to Sub-sections 1 through 3 in which Prof. I. I. Glass deals very thoroughly with the detailed theory and performance of idealized, cold-driven constant-area shock tubes.

In Sub-sections 4 through 7, Mr. J. G. Hall treats the production of strong shock waves as well as the application and design of and the instrumentation for conventional shock tubes.

In Sub-section 5, rather than to attempt a detailed discussion of the results of specific researches, the intent has been to illustrate the method of application and to provide ample documentation. Sub-section 6 is concerned with the general design and construction aspects which are common to most applications and is limited to conventional shock tubes with diaphragms.

In Sub-section 7, the emphasis is placed on the aerodynamics side and on instrumentation and measuring techniques which have been reasonably well tested and proven; at the same time the direction of future developments in this important area is indicated.

The material is directed primarily to those whose research activities include the use of shock tubes. However, everyone actively engaged in research in the region of hypersonic flow of gases would be well advised to take note of this up to date compendium of the present state of the art and the accompanying extensive bibliography. This volume is excellent value for $3.75.

For those who do not have direct access to a copy of this report, it will be of interest to note that UTIA Report No. 12 (Parts I and II), Toronto 1958, contains essentially the same material.

R. J. Ross

High Altitude Aircraft Equipment. By L. T. Bykov, M. S. Yegorov and P. V. Tarasov. Pergamon Press, New York, 1961. 430 pages. Illus. $15.00.

Apart from the political overtones, especially those encountered in the first chapter, the book presents a good balance between the theoretical and practical approaches. There is a liberal sprinkling of sketches of typical equipment, together with detailed explanations of the methods of operation. In most instances the design formulae are presented together with a full development from basic principles. However, in the few instances where an empirical approach is used, the text suffers in that reference to the source of the data is inadequate.

The comfort zone of cabin temperature and pressurization corresponds approximately to those in use on the North American continent, the ambient temperature and pressure for the standard day being those described in the International Tables.

The dynamic stability analysis of the control system and components, a subject given little consideration in similar publications, is discussed at great length. However no mention is made of the usually accepted method of damping cabin temperature fluctuations by means of a rate of change anticipater. The section on cabin refrigeration is rather short, giving little more than the description of the units involved. There is no mention of the relative merit of the various types of air cycles and their effect on aircraft performance.

Although the technical presentation is good, the book as it stands is somewhat marred by the presentation of the curves in metric units, making direct comparison with standard data tedious.

This book is intended primarily as a textbook for use as an introduction to the subject of high altitude aircraft equipment and, as such, is among the most concise publications that I have read. I would recommend this book to any graduate engineer leaving university and wishing to specialize in this particular field.

D. Jones

The Stability of Motion. By N. G. Chetayev. Translated by M. Nadler. Pergamon Press, New York, 1961. 200 pages. Illus. $9.50.

In a brief foreword the publishers apologize for the price of the book and also for the necessity of using the methods of photolithography instead of normal printing. The reasons given for these unfortunate necessities are the cost of translation, the limited market available to works of such an advanced nature, and the need for speedy production.

The book itself is undoubtedly a fine contribution to the literature of the stability of motion. It is based upon the methods of Lyapounov, whose methods are widely used in Russia but are not so well known outside Russia. Consequently this is an important book. In order to understand the book the reader must be familiar with dynamics, at least up to the equations of Lagrange and Hamilton.

In spite of the fact that the book is only 200 pages, it covers, in its ten chapters, a remarkably wide variety of topics. The first four chapters deal with the fundamental principles of the subject, including the Lyapounov principles themselves, the secular equation, whose roots are of importance in problems of dynamical stability, and an excellent account of the theory of linear differential equations with constant coefficients. The proof of each theorem is followed by at least one example constructed not only to illustrate the theorem and its proof but also to illuminate its motivation. This desirable practice is continued throughout the book and makes it much easier and pleasanter to read. The remaining six chapters deal with applications ranging from the effects of perturbation forces on equilibrium to problems of transient and periodic motion. Among the examples occurs a discussion of the stability of an aircraft in steady state rectilinear flight.

Considering the complex nature of its contents the book is written with great simplicity of style and is attractive to read. It is singularly free of misprints, especially among the formulae where a misprint can wreak such havoc. The only example of a misprint which the reviewer could find was in the discussion of the stability of the motion of a top spinning under gravity. The angle between the axis of symmetry of the top and the vertical is referred to as the mutation angle instead of as the nutation angle.

The book can be thoroughly recommended to all those who are interested in problems of dynamical stability.

Prof. C. Fox

Gas Sampling and Chemical Analysis in Combustion Processes, Agardograph 47. By G. Tine. Pergamon Press, Oxford, 1961. 94 pages. Illus. $6.00.

This new Agardograph is concerned with the two problems of gas sampling and chemical analysis of combustion gases. The sampling techniques available today have evolved on the test bed as a means of obtaining comparative data as parameters, such as the mixture ratio, are changed during test. As the author points out the chief problem is to ensure that the sample is obtained without disturbing the flow or affecting the chemical composition. Up to the present a largely intuitive approach has been used in the attempt to determine the best sampling procedure. In view of this it is quite surprising to discover that the results have on the whole been meaningful. This monograph will more than justify itself if it stimulates a more fundamental study of the problems encountered in gas sampling.

In the field of chemical analysis, a thorough review of the various methods now available to the research worker is made. In particular, estimates of the time needed for a given type of analysis will be of value to those selecting analytical procedures or purchasing the more modern, and relatively expensive, types of equipment.

This book is a most useful contribution to the literature and will be of considerable value to research workers in universities and industrial organizations.

L. A. DICKINSON

Modern Flight Dynamics. By W. R. KOLK. Prentice-Hall, Inc., New Jersey, 1961. 288 pages. Illus. $10.00.

This book is a product of the aeronautical-astronautical industry, its author W. R. Kolk being a systems engineer at United Aircraft Corporation. As pointed out by Professor Shatswell Ober in the Foreword, the background of the book is the author's "rough-edged industrial practice, where immediate results, not merely solutions were demanded . . . useful to solve the many different problems he experienced". The book must be judged in the light of this statement, i.e. as a practical rather than a scholarly work. The author's experiences in industry have undoubtedly been the primary factor governing his choice of topics, which is not well balanced from the standpoint of a general coverage of the stability and control of aircraft and spacecraft. The industrial background of the author is probably also a factor in the quality of the mathematical and analytical derivations, which do not come up to the standard of scholarship and accuracy one would expect from a research laboratory or a university.

Neither the author, the publishers, nor Professor Ober have stated exactly what the objective of the book is. This must be inferred from the title, from the statement in the preface " . . . emphasize the analytic foundations of dynamic motion . . .", and from the contents themselves. These are indicated by the Chapter headings: (1) Mechanics and Equations of Motion; (2) Direction Cosines and Euler Angles; (3) Aerodynamic Forces and Moments; (4) Modes of Motion; (5) Longitudinal Motion; (6) Lateral Motion; (7) Roll Coupling; (8) Flying Qualities; (9) Reversible Control System; (10) Irreversible Control System; (11) Aero-structure-control Interactions; (12) Rockets: as they Tumble and Spin; (13) Celestial Mechanics. There are also five appendices. From the choice of contents, and from the manner of the treatment, the book is aimed more at the practising engineer than at the student. It covers a set of problems in dynamics and control which are of particular interest to the author and which range widely over the field of aerospace vehicles. It will not likely be found useful as a pedagogical aid, in view of the above, and because of a lack of clarity, lack of soundness, and undefined symbols in the detailed mathematics.

Aeronautical engineers will find certain sections useful. Particularly noteworthy are the emphasis on direction cosines and coordinate transformations in Chapter 2, the modern information on flying qualities in Chapter 8, and the contents of Chapters 9, 10 and 11, which are not to be found in any other text on the subject. The aerodynamic content is disappointingly thin – Chapter 3 contains little that is useful or instructive. The classical ideas of neutral points and manoeuvre points are relegated to an appendix, and what is even more surprising, so is the longitudinal response to elevator deflection. Chapter 4 is really about degrees of freedom, not normal modes, as might be thought from the title. An interesting analysis (new to the reviewer) of the flight path of a tumbling rocket is contained in Chapter 12. However, the later sections of this chapter are rather spoiled by a lengthy treatment of spinning rockets which omits aerodynamic forces altogether – eight pages of it are devoted to diagrams of examples of classical precessional motions.

Finally, the style of writing must be mentioned. The author uses a breezy, semi-humorous style, e.g. "Such a deduction, when applied to a conflagration the size of that ascribed to Mrs. O'Leary's cow would have had the buildings rambling about in absolute mayhem". This style will undoubtedly appeal to many readers, in spite of the fact that it frequently serves to conceal a lack of clarity. Your reviewer is not, unfortunately, among these, and could take the book only in small doses.

In summary, this book will be a useful addition to the libraries of many companies and practising engineers. In spite of its shortcomings, the reviewer welcomes it as an addition to his own bookshelf. However, students should keep clear of it in order to avoid confusion, until they have advanced beyond their basic courses in mechanics of flight.

PROF. B. ETKIN

Interavia ABC 1961 — World Directory of Aviation and Astronautics. Interavia S.A., Geneva 11, Switzerland, 1961. 1325 pages. $12.00.

The ninth edition of the Interavia Directory is as imposing as its predecessors. It is divided into four main sections: "Alphabet", which is an alphabetical listing of companies and organizations; a section called "Analyt", which lists the whole gamut of aeronautical endeavour, by countries or continents or (a rather unsatisfactory resort) part-continents, such as East-Europe, meaning the Iron Curtain countries including the U.S.S.R.; a section called "Indicator" which is a five-language glossary of terms; and "Who is Where", which is an alphabetical listing of all the people listed by their positions in the Analyt section. This coding and cross-referencing is meticulous, though the inclusion of "Elizabeth II, H.M. Queen G. Britain" in Who is Where seems to be carrying the fancy to the ultimate.

It is easy to pick holes in a work of this size. For instance, in the various references to the IAS there is a good deal of inconsistency between Aerospace and Aeronautical. Printing errors are commendably few, though there is a hot one in the listing of the present President of the RAeS. In this connection, the main weakness of the Directory as a reference lies in the fact that it is inevitably out of date. Many organizations such as technical societies change their Executives every year and it is questionable whether it is worth the effort to list the names, titles, ranks, honours and awards of so many people who are no longer in office. The CAI listing is technically correct, because we took the precaution to add "1960-61" to the listing of our Council and Branch Chairmen (but we forgot the Section Officers) when the proofs were submitted; but even so last year's information is not much good to anybody.

Carping is rather a fruitless occupation, and by and large it can be said that the Interavia ABC is a very thoroughly prepared and very valuable work of reference for anyone concerned with the broad picture of world aviation. It is remarkably cheap at the price.

H. C. LUTTMAN

Full Scale Fatigue Testing of Aircraft Structures. By F. J. Plantema and J. Schijve. Pergamon Press, New York, 1961. 426 pages. Illus. $15.00.

This book contains papers read by leading international specialists at the Symposium held in Amsterdam, 5-11 June, 1959.

The first paper by A. F. Hardrath of the USA briefly reviews the factors involved with fatigue in aircraft structures. It is a most clear and concise presentation which sums up the situation extremely well. The next paper by E. Gassner and W. Schutz of Germany presents experimental data showing a relationship between program loading tests and one level tests, providing the latter are conducted at the maximum stress of the load spectrum. However, the conclusions state that the relationship is somewhat limited at present and emphasizes the necessity of program tests for establishing the structural airworthiness. J. Schijve of the Netherlands next considers the value of three well known methods of estimating the fatigue life of a component. The discussion is based on a large number of program-fatigue tests conducted on riveted lap joints.

The paper by J. Kowalewski of Germany is concerned with the relation between fatigue lives under random loading and under corresponding program loading. This is an extremely interesting paper which includes details of the test equipment used in the experiment. The specimens used were simple notched round bars.

The paper by A. O. Payne of Australia is again concerned with the fatigue testing of Mustang wings but does appear to contain some new data from the already well published data presented by Payne at other symposia. W. B. Huston of the USA presents a paper of a similar nature to that by Payne, except in this case C46 wings were fatigue tested using two types of loadings, constant level and randomized step. W. J. Crichlow of the USA presents a paper on the methods of analysis for the ultimate strength of damaged structures, with correlating test data. This is an excellent paper and must rank as one of the best at the symposium, at least from the aircraft engineer's viewpoint. Crichlow presents data for flat and curved panels, both stiffened and unstiffened. There is a mass of test data to back up some of his curves; however, others are drawn from little data.

The paper by W. J. Winkworth of the UK is concerned with the test equipment and test procedures used at RAE. The paper is very well presented and it does underline the basic requirements associated with full-scale fatigue testing. V. Villa of Italy presents a short paper on the background of full-scale testing in Italy. It is interesting that full-scale aircraft structures were being fatigue tested there during the Second World War.

The paper by W. Barrois of France discusses the philosophy of fatigue testing of large dimension aircraft structures. The interesting items he considers include the establishment of the loading spectrum expected in service and the strength criteria after initial failure.

The next two papers, one by R. Larre and one by P. Vallat, both of France, are concerned with the Caravelle fatigue program. The first paper discusses very thoroughly the installation developed for the Caravelle test program and includes several photographs and a diagram of the hydraulic loading system. The second paper presents the complete structure fatigue tests, development, and analysis program in detail. The flight plans, the procedures for initiating inspection guidance to operators, and many other details, all of practical use, are presented. D. R. Samson of the UK illustrates the procedure adopted to demonstrate the airworthiness with respect to fatigue of the Jet Provost T.Mk. 3 trainer. Of most interest in this paper are the results of the flight test program which showed that the most outstanding loading for fatigue was that caused by spinning. The next paper by E. Van Beek discusses the full-scale fatigue tests on the Fokker Friendship. Among the items presented are the flight plans, details of the failures that occurred, the methods used to improve the structure, and a conclusion that a pure safe-life approach to the fatigue problem is technically speaking unacceptable due to the weight consequences involved.

The paper by L. Locati and G. Sarzotti of Italy considers the fatigue ratio for the design evaluation of structures, this being the ratio of fatigue strength to the tensile strength. It is a fascinating paper and Table 1, which evaluates the test results, shows the fatigue ratio for three endurance values for a wing, fuselage, aileron, elevator etc. Comparison of data with Payne's Mustang wings and the RAeS data sheets are presented.

W. Nicole of Switzerland presents some results of fatigue tests with parts of vital importance of the Ground-Attacker P-16. Of particular interest is the test program on ball bearings.

The paper by W. T. Koiter on airworthiness requirements for fatigue strength is excellent. After discussing the shortcomings of the present day requirements, he then presents the proposed requirements prepared by the Netherlands Committee on Structural Strength Requirements for Civil Aircraft in April 1958. These requirements, superior to the existing requirements, may help to reduce the present day fatigue problems. However, the fatigue performance of aircraft structures is primarily in the hands of the designer and the airline maintenance engineer. Certain basic rules for designing a safe structure have been established over the last few years and it is doubtful if more rigid requirements would reduce the present fatigue failure rates.

The next paper by Bo Lundberg of Sweden is very similar to that of Koiter in so much that Lundberg considers a quantitative statistical approach to the aircraft fatigue problems as the answer to safety. Of particular interest is the discussion dealing with fail-safe structures and their probability of failure based on inspection periods. Some individuals have the mistaken idea that if a structure is fail-safe, then inspections are relatively unimportant. Lundberg points out that the safety of a fail-safe structure to a very large degree depends on the length of the inspection interval.

The final paper by R. M. Ferrari, I. S. Milligan, M. R. Rice and M. R. Weston of Australia, is titled "Some Considerations Relating to the Safety of 'Fail-Safe' Wing Structures". Again this paper is attempting to establish some practical airworthiness standard. The probability of a crack developing, and its consequent effects on the residual strength, plus the probability of encountering a sufficiently high failing load, is investigated by the use of an example.

In conclusion, therefore, it can be stated that this book contains an excellent selection of papers and is strongly recommended to all aircraft engineers, whether directly associated with fatigue or not. Not only are the papers of value, but the discussions at the end of each paper contribute to the book's usefulness. The editors should be complimented on arranging such an interesting collection of papers which consider most aspects of fatigue close to the aircraft engineer's routine work.

E. Aubrey

TEST PILOTS SECTION SYMPOSIUM

FLIGHT IN THE FRINGES OF SPACE

at

R.C.A.F. STATION UPLANDS

17th November Morning 10.00 a.m.

PHYSIOLOGY

Visit to the
Institute of Aviation Medicine Laboratory
at the DRML, Downsview

Introduction

Physiological Problems Associated with Space Equivalent Flight
W/C W. G. Leach, Officer Commanding
and
W/C R. A. Stubbs, Project Coordinator
Flying Personnel Medical Establishment

17th November Afternoon 1.00 p.m.

AERODYNAMICS

Luncheon in the Officers' Mess,
RCAF Station Downsview
followed by
Flight in the Transition Region of the Upper Atmosphere
Dr. G. N. Patterson
Director, Institute of Aerophysics
University of Toronto

18th November Morning 9.30 a.m.

NAVIGATION

Chairman
CDR E. B. Morris
Director of Aircraft Maintenance, RCN
Vice-Chairman, Test Pilots Section

Advanced Flight Data Systems
Mr. C. S. Bridge, Director, Systems Management
and
Mr. G. P. Zemlin, Program Manager, Flight Data Systems
Guidances and Control Systems Division
Litton Systems, Inc.

FLIGHT TEST

Chairman
Mr. R. J. Baker
Flight Test Engineer-Pilot, TCA
Past Chairman, Test Pilots Section

Altitude Explorations with the X-15
Mr. J. Walker
X-15 Project Pilot
NASA Flight Research Center

(Luncheon and Bar will be available at the Officers' Mess, after adjournment.)

17th November Evening 7.30 for 8.00 p.m.

DINNER

at the Officers' Mess,
RCAF Station Uplands

Chairman
W/C R. G. Christie
Directorate of Air Defence and Strike Operations, RCAF
Chairman, Test Pilots Section

Guest
Mr. J. Walker
X-15 Project Pilot
NASA Flight Research Center

Principal Speaker
Dr. J. E. Keyston
Vice-Chairman, Defence Research Board
Public Opinion and National Defence

C.A.I. LOG

SECRETARY'S LETTER

EIGHTH ANGLO-AMERICAN CONFERENCE

Unquestionably the most important event of the past month was the Anglo-American Conference held in London from the 3rd to the 14th September. In 1959, when the Conference was held in New York, with a side trip to Toronto, the CAI was participating for the first time and somewhat timidly. This time I felt our feet much more firmly on the ground and I was disappointed that we could not muster a larger Canadian delegation for the occasion. The CAI delegation amounted to 9, compared with 81 from the IAS. Our showing could have been better; for wherever I went in London I kept meeting CAI members, over for the SBAC Show etc, who for one reason or another had not taken in the Conference while they were about it. They missed a very enjoyable and valuable experience and, since it was confined to members of the three societies, they wasted one of the better privileges of membership.

The Conference was centred on the new RAeS Lecture Theatre and it merits a brief description. With a few minor modifications, which are being put in hand, it will be the last word in lecture theatres. It extends from RAeS Headquarters into what was once its garden. It seats 310, a convenient size for normal purposes but rather too small for a Conference of this magnitude; even so, the proceedings were piped to other parts of the building and it was possible to hear everything (and follow the figures in the preprints) in comfortable chairs in the other rooms.

The walls of the Theatre are finished in "corrugated" ash and the acoustics are good, even without the aid of the public address system. The projection equipment is excellent. Blackboards fold neatly away into the wings. In fact it has all the trimmings that a lecture theatre ought to have. The body of the hall is decorated with portraits of Past Presidents and, above them, the crests of the three Divisions (Australia, New Zealand and South Africa) and of the Branches of the Society. The five high-backed chairs on the stage are of teak finished in blue leather upholstery, with the Society's crest in gold, and they are truly magnificent. The President's Chair, presented by Sir Roy Fedden, is altogether too elaborate to describe here; it was described in the June issue of the RAeS Journal. The other four match it and bear plaques indicating that they were presented, respectively, by the three Divisions and the Branches. The lecterns on either side of the stage similarly bear plaques recording the contributions of the IAS and the CAI.

At the Opening Ceremony on the 3rd September: (l to r) Dr. Guyford Stever, President IAS, A/M Sir Owen Jones, President RAeS, Mr. H. C. Luttman, Secretary CAI—acting for the President who had not arrived at this time—and Mr. S. P. Johnston, Director IAS.

By no means the least valuable asset of the Lecture Theatre is its roof, which provides a very pleasant and convenient place for social gatherings, buffet lunches and the like, when the weather is fine; and it was fine all the time we were there.

There was a Reception in the Lecture Theatre and a short Opening Ceremony on the 3rd September. Thereafter the first week was devoted to visits to various plants and establishments. On the Monday we were flown north by Vanguard and some of the party visited Jodrell Bank but I, personally, went to English Electric. (I met Mr. C. R. Shawyer there and I am sure that his many friends in Canada will be glad to know that "Snowy" is the same as ever.) On the Tuesday and Wednesday we went to Farnborough. On the Thursday I visited the NPL at Teddington, while some of the other CAI delegates

went to De Havilland Engines I believe. On the Friday I visited Handley Page at Radlett and Cricklewood; the alternative visit that day was to Westlands. It was a full week and I think that most of us were glad to get our feet up at the end of it.

The President and Mr. Richmond were scheduled to chair two of the sessions of the lecture programme in the second week but unfortunately Mr. Richmond was called away on business; his place was taken by Mr. R. D. Hiscocks, who explained his qualifications by saying that he was "a Canadian and available at a moment's notice"; he proved a most worthy substitute. Dean D. L. Mordell and Mr. D. C. Whittley presented the two Canadian papers on the programme. The RAeS and IAS provided six papers each. In addition, the programme included the Wilbur Wright Memorial Lecture, given by Dr. Abe Silverstein, in the evening of the 12th September. This was a very fine lecture indeed.

The Conference ended with a Dinner-Dance at the Dorchester on the 14th September.

This year the lecture programme was based on three themes, Space, Supersonic Transport and VTOL. I thought that it was, in consequence, a very much better programme than that of previous Conferences, which have tended to be too diverse. It was a useful exchange of views between the three countries. But perhaps the greater value of these Conferences lies in meeting people, old friends and new friends, and just talking shop with them. These contacts are part of our professional life just as much as the strictly technical activities; they pay huge dividends and I wish that the fact could be more generally recognized.

CAI DINNER IN LONDON

On the 11th September we took the opportunity of having the President in London to hold a CAI Dinner at the Washington Hotel. It had been organized by W/C E. E. McCullough of the Canadian Joint Staff, London, and he deserves our thanks for a very happy evening. There were 25 of us present, including such Honorary Fellows as Sir George Dowty and the Secretaries of the RAeS and IAS, Dr. A. M. Ballantyne and Mr. R. R. Dexter respectively. Mr. Charles Tilgner, Vice-President of the IAS and a long-time member of the CAI, was also with us. I could go on listing the whole 25 of them but I must restrain myself.

It was a great success and we were urged to repeat it whenever we can get a President to London in future.

MAN-POWERED FLIGHT

Also while I was in London I managed to meet some of the RAeS Man-powered Aircraft Group and had dinner one evening with Mr. B. S. Shenstone of BEA (and the CAI), Mr. David Rendel of the RAE and Mr. G. M. Lilley of Cranfield. We had a very interesting conversation. Two of the three projects supported by the RAeS are expected to fly quite soon – whether they will win the Kremer Prize is perhaps another matter. I was strongly advised that we in Canada should quit our rather modest efforts to encourage small research projects and should go boldly out to raise some money and get something built.

If we could get a fund started, I feel sure that it would snowball; for there is a good deal of popular interest in the subject and considerable publicity to be gained by donating to the cause. The British advice is obviously sound and I shall pass it on to our Man-powered Flight Committee for consideration.

TEST PILOTS SECTION SYMPOSIUM

This month we include with this Journal another of our new-type meeting notices. I hope that many members, of the Ottawa Branch in particular, will try to attend the Dinner on the Friday evening and the technical sessions on the Saturday.

The topic "Flight in the Fringes of Space" reminds me of the story about the headline in a British newspaper "FOG IN CHANNEL. CONTINENT ISOLATED". It's a matter of point of view.

2.4.1.

THE ROYAL AERONAUTICAL SOCIETY

THE AERON~~AUTICAL SOCIETY~~ OF CANADA

THERE was an informal meeting held on September 1st at the offices of Messrs. Fetherstonhaugh & Co., 10 King Street East, Toronto, to discuss the formation of an Aeronautical Society (to be called "The Aeronautical Society of Canada") for the purpose of giving a stronger impulse to the scientific study of aerial navigation and to promote intercourse among parties interested in aeronautics in Canada, and to aid with advice and instruction those studying the subject.

The foregoing is but an outline of the aim of the Society, but putting it more in detail, it is intended to make arrangements for the reading of papers and their discussion; to get up lectures, both popular and scientific, from time to time, and to issue, when possible, the proceedings of the Society in printed form; to form a library, from which books may be borrowed by members; and, if possible, to arrange for the starting of an Aeronautical Journal, to be published in Canada, which will be the official organ of the Society.

It is without doubt an urgent necessity that a society of this description should be at once formed in Canada, as the time is not far distant when we shall see the "Car in the Air" a commercial reality.

It is therefore high time that Canada should not be lagging behind, but should put forward her best efforts to bring herself into line with all the great countries of the world. In the United States the Government has gone so far as to place a duty of 40 per cent. on all flying machines entering that country.

It is sincerely trusted that this circular will bear a rich harvest, therefore the Sub-Committee ask you to give your best support to this organization, and aid all you can in furthering its aims and increasing its membership.

A general meeting will shortly be called and we ask all those who have the smallest interest in Canada and things Canadian to send in their names so that the Secretary may communicate with them when arrangements have been made as to the time and place of this meeting.

Should you wish to become a member of this Society or should you have friends or acquaintances whom you think would be likely to join the Society, kindly send their names and addresses and forward all communications to M. B. Logan, Esq., Secretary pro tem., 99 Gloucester Street, Toronto.

FORM. *If you are interested in this subject and propose becoming a member, kindly fill in and send to M. B. Logan, Esq., Secretary pro tem., 99 Gloucester St., Toronto*

Name..

Address—

Can you help the Society in the way of loaning of books, papers, etc., on Aeronautical subjects, lending of plates or lantern slides? Would you be prepared to give a paper or a lecture on some subject connected with Aeronautics, in fact can you help the Society in any way whatsoever? If so, kindly state here below:

Also kindly write here the names and addresses of friends whom you think will be interested in the subject of Aeronautics.

AERONAUTICAL SOCIETY OF CANADA

While I was in London, Mr. F. H. Smith, the Librarian of the RAeS, gave me a photostat copy of a notice about a proposed Aeronautical Society of Canada. It is reproduced here – not very legibly I admit but one cannot expect much from a double reproduction from a rather weary original.

I should like to know more about it. It is undated and perhaps the only clue is the name of the Secretary, Mr. M. B. Logan of 99 Gloucester Street, Toronto. Can any of our members shed any light on it?

Incidentally the photostat was prepared for me, with some difficulty, by Mr. Smith's secretary, Miss Cody, who is a granddaughter of the great Col. S. F. Cody. There is some significance in all these historical connections, though I am not sure what.

BRANCHES

Montreal — 18th August

We have now received further particulars of the Montreal Branch Golf Tournament held on the 18th August and briefly mentioned in the last issue. The tournament took place at St. Andrews East, P.Q., in perfect weather

and 118 members and guests participated. Among the many prizes the most important were,

The E. B. Schaefer Memorial Trophy won by Mr. D. F. MacLaren;
The Bob Wright Memorial Trophy won by Mr. A. Nicholls; and
The Ross Trophy, open to non-members, won by Mr. C. Saylor.

I understand that the tournament and buffet dinner were financially successful too!

Quebec — 31st August

This meeting was called a "Soirée Technico-Vineuse" and it was generously supported by Le Comité National des Vins de France. As if this were not enough, the Branch members provided some more bottles and assorted cheese, biscuits etc. French Embassy officials and Laval professors were invited and in all about 160 people attended.

Of the seven varieties of wine, four were sampled before the "Technico" part of the meeting and three afterwards. The speaker was Col. Rupied who spoke, in French, on the resources of the French Aircraft Industry and this was followed by a French film on Production Aéronautique. The Embassy also supplied a good deal of French technical literature on aerospace matters, which members could take to read at home.

Not surprisingly the meeting is reported to have been a great success.

Edmonton — 13th September

The Edmonton Branch met in the RCAF Mess, Kingsway, on the 13th September. Films on the Hercules C-130 aircraft were shown, with a commentary given by Mr. K. A. Porter of the Lockheed Aircraft Corporation. Twenty-six members attended.

Cold Lake

Mr. C. B. Jeffery, the Branch Chairman, is being moved to Ottawa in the near future and his duties are being taken over by the Vice-Chairman, Mr. W. R. Fryers.

ANNOUNCEMENTS

NEWS OF MEMBERS

R. A. Neale, F.C.A.I., who left Canadair as Vice-President, Manufacturing, in 1957, after 10 years with that Company, and has since been living in Seattle, has been appointed Manager of Operations of the General Dynamics Convair Division at San Diego.

Dr. H. S. Ribner, F.C.A.I., has returned to the Institute of Aerophysics, University of Toronto, after spending a year at the University of Southampton.

J. L. Brisley, A.F.C.A.I., formerly of De Havilland Aircraft of Canada Ltd., has been appointed Contract Engineering Manager, Godfrey Engineering Co. Ltd.

W/C C. W. Blain, M.C.A.I., has been transferred from the Royal Military College, Kingston, to RCAF Station Trenton as Chief Technical Services Officer.

R. J. Landry, M.C.A.I., has been appointed Canadian Sales Manager of the Hiller Aircraft Corp. His office will be located in Ottawa. For the last two years Mr. Landry has been Secretary of the Industrial Council, AITA.

A. R. G. Leckie, M.C.A.I., Head of the Dept. of Aeronautics, Southern Alberta Institute of Technology, who has spent the last year in England, has returned to Calgary.

L. F. McCaul, M.C.A.I., formerly with Orenda Engines Ltd., has been appointed Sales Representative, Fleet Manufacturing Ltd.

S/L K. F. Shepard, M.C.A.I., has completed his course at the College of Aeronautics, Cranfield, and returned to take the position of Acting Head, Mechanical Engineering Dept., Royal Military College, Kingston.

Mrs. G. J. Ellison, Associate, the first lady member of the Institute, has moved from Vancouver to Stockholm, Sweden.

DEATH

It is learned with great regret that **R. J. Burden, M.C.A.I.,** died on the 16th August. At the time of his death he was Chief Engineer, Canadian Pacific Air Lines, Ltd.

SUSTAINING MEMBERS

The following companies recently joined the Institute as Sustaining Members,

Aluminum Company of Canada Limited
Wheeler Airlines (1960) Limited

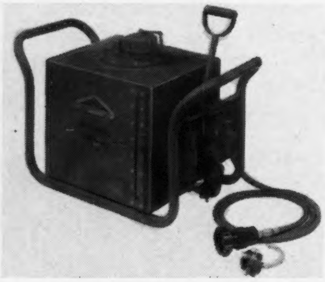
Canadair Ltd. has announced an increase in the gross takeoff weight of the CL-44 to 210,000 lb. This increase, brought about by minor structural modifications, has made available a still-air range of 3,250 miles with 63,900 lb of payload. The full-fuel payload, with allowances for reserve and ground manoeuvering, has been raised to 37,300 lb for a range of 5,660 miles.

In addition, the Minister of National Defence has announced that the RCAF will procure the side-by-side two-seater CL-41 jet trainer, which has been designed and

developed by Canadair Ltd. It is understood that the initial order will be for 190 aircraft.

Garrett Manufacturing Ltd. has developed a pneumatic signal generator to serve as a portable pressure standard for laboratory and field use. It has already been applied as a pitot-static simulator for calibration and test of the Central Air Data Computer on the CF-104. In this application, it provides stabilized pneumatic signals, for pitot pressure, from 1.5 to 110 inches Hg Abs and, for static pressure, from 0.5 to 35 inches Hg Abs; it also provides pneumatic ramps corresponding to 1 M/min and 30,000 ft/min, each constant within ±2%, and sinusoidal pressures of variable amplitude and frequency, with 5% maximum distortion. It is an extremely versatile source of control of pneumatic pressures, applicable to all pneumatically operated devices in the atmospheric range.

Godfrey Engineering Company Ltd. has developed a portable hydraulic fluid dispenser (see cut) suitable for topping up pressurized reservoirs or auxiliary tanks. Its empty weight is 45 lb, with a capacity of 14 Imp. gals. It has a delivery rate of 1.6 Imp. gals/min at 60 psi and embodies a 10 micron filter and 15 ft of hose with a self-sealing coupling.



Jarry Hydraulics Ltd. announces that a minority interest in the Company has been acquired by the Dominion Brake Shoe Company, Ltd. This association, which will not entail any changes in management or personnel of Jarry Hydraulics, will have considerable commercial advantages to both Companies.

INSTITUTE OF RADIO ENGINEERS

Affiliate Plan

The Canadian Aeronautical Institute has been accepted as a recognized organization whose members are eligible to affiliate with the IRE Professional Groups. Full particulars and application forms may be obtained from CAI Headquarters.

An Affiliate receives many of the privileges of membership, including the literature and the right to attend meetings of the Professional Groups to which he belongs—for fees of the general order of $7.50, depending on the Group. The Professional Groups include Aerospace and Navigational Electronics, Space Electronics and Telemetry, Electronic Computers, Instrumentation and many others in which CAI members may be interested.

LIST OF MEMBERS—CORRECTIONS

An error was made in listing the **Vancouver Branch Publications Committee** in the List of Members for 1961. The Committee should be: Mr. A. Uydens, Chairman, Mr. B. Towler and Mr. J. A. Love.

In addition it has been found that

Kadlec, L. (AF), 43-10 Kissena Blvd., Flushing 55, N.Y. was inadvertently omitted from the main listing.

APPOINTMENT NOTICES

The facilities of the Journal are offered free of charge to individual members of the Institute seeking new positions and to Sustaining Member companies wishing to give notice of positions vacant. Notices will be published for two consecutive months and will thereafter be discontinued, unless their reinstatement is specifically requested. A Box No., to which enquiries may be addressed (c/o The Secretary), will be assigned to each notice submitted by an individual.

The Institute reserves the right to decline any notice considered unsuitable for this service or temporarily to withhold publication if circumstances so demand.

Positions Vacant

Project Engineer (Electrical/Electronic): with at least five years experience in the design of airborne electrical and electronic installations. Duties will include preparation of schemes and supervision of a small section of draftsmen engaged on wiring and interconnecting diagrams, and advising a group of technicians working on the repair and overhaul of electronic equipment. Familiarity with RCAF procedures and drawing systems would be advantageous. Minimum educational requirement, British Higher National Certificate in Electrical Engineering, or equivalent. Age 30-45. Salary according to experience and qualifications.

Excellent benefit program after a short probationary period. Assistance with relocation expenses to be discussed with successful applicant. Apply to Manager Industrial Relations, Northwest Industries Limited, Box 517, Edmonton, Alberta.

COMING EVENTS

IAS/CAI

23rd-24th October 1961 – CHATEAU LAURIER, OTTAWA; *Joint Meeting*

ASQC

28th October 1961 – ECOLE POLYTECHNIQUE, MONTREAL; *Annual Forum, Quality Control Increases Productivity*

BRANCHES

Quebec

15 November – LAVAL UNIVERSITY; *Measurement of distance in Space*, Lt. Col. J. A. Stairs, DND

Edmonton

8 November – RCAF OFFICERS' MESS, KINGSWAY; G/C W. M. K. Carr

13 December – RCAF OFFICERS' MESS, KINGSWAY; *DC-8 Maintenance*, Speaker from CPA.

Tour Speakers

A Review of the Problems of Satellite Rendezvous
K. J. Radford, RCAF
13th November – VANCOUVER
14th November – CALGARY
15th November – EDMONTON
16th November – WINNIPEG

Engines for V/STOL Aircraft
Dr. S. G. Hooker, Bristol Siddeley Engines
14th November – TORONTO
15th November – MONTREAL
16th November – OTTAWA

SECTIONS

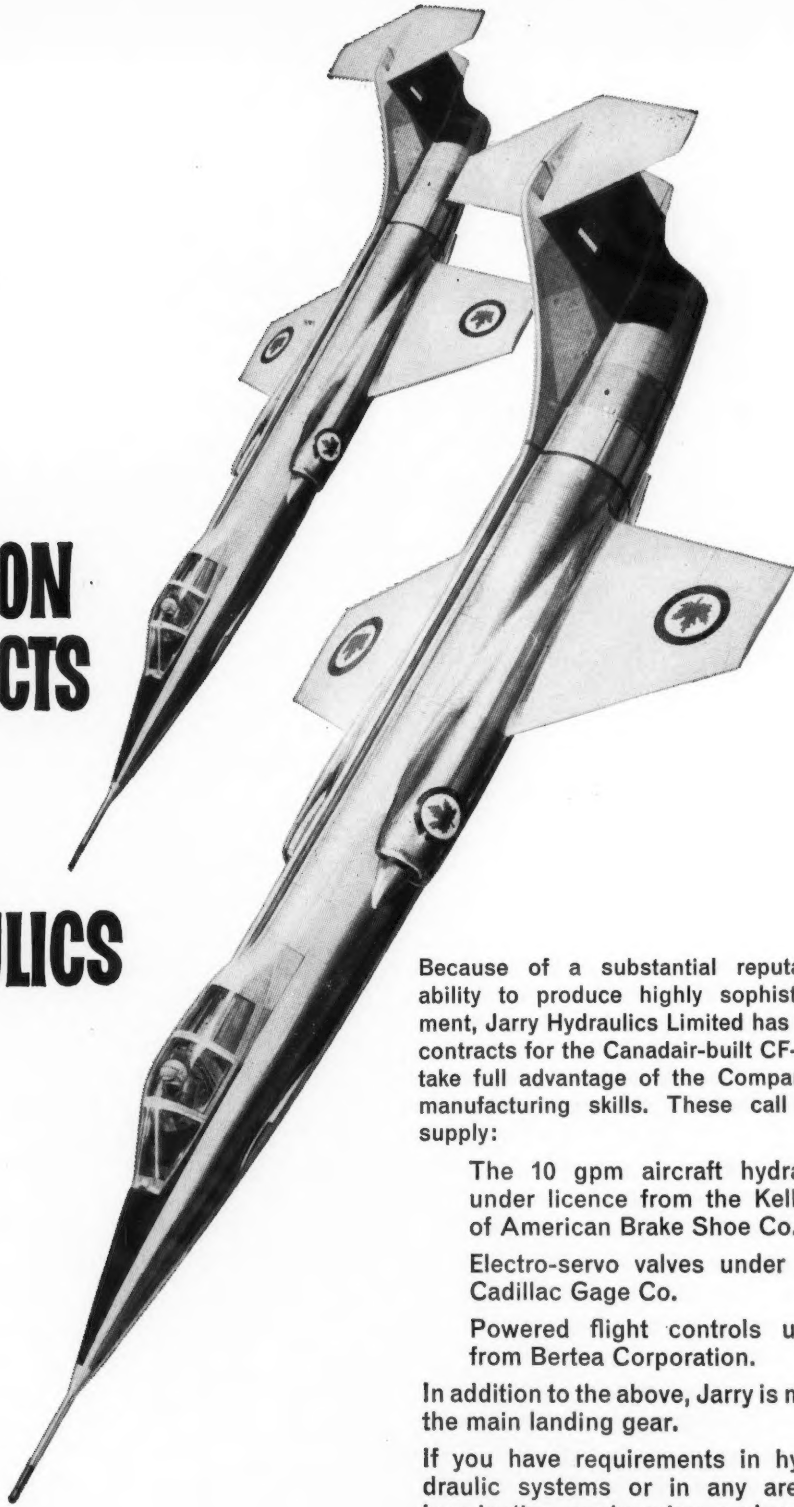
Astronautics

26th-27th October – UTIA, TORONTO; *Interplanetary Explorations*

Test Pilots

17th-18th November – RCAF STN. UPLANDS, OTTAWA; *Flight in the Fringes of Space*

CF-104 PRECISION CONTRACTS TO JARRY HYDRAULICS



Because of a substantial reputation for the ability to produce highly sophisticated equipment, Jarry Hydraulics Limited has been awarded contracts for the Canadair-built CF-104 which will take full advantage of the Company's precision manufacturing skills. These call for Jarry to supply:

> The 10 gpm aircraft hydraulic pumps, under licence from the Kellogg Division of American Brake Shoe Co.
>
> Electro-servo valves under licence from Cadillac Gage Co.
>
> Powered flight controls under licence from Bertea Corporation.

In addition to the above, Jarry is manufacturing the main landing gear.

If you have requirements in hydraulics, hydraulic systems or in any area calling for imaginative engineering and precise manufacturing talk to Jarry.

JARRY HYDRAULICS LTD. • MONTREAL 18, CANADA